Assessment of the

Ground and Surface Water Quality

in the

Spirit Creek Watershed

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Executive Summary

Operation of three hog barns (by Big Sky Farms) was approved for the Good Spirit Lake Area in 2000. In response to this approval, the *Friends of Good Spirit Lake Stewardship Group* hosted a meeting for both proponents and opponents of the hog operations to share their concerns and points of view. Concerns about potential impact of hog barn operations on water quality, soil condition and air quality in the Upper Assiniboine River Basin were raised. The *Spirit Creek Watershed Monitoring Committee* (SCWMC) was appointed by the Honourable Clay Serby (then Minister of Agriculture, Food and Rural Revitalization) in response to the approval of a multi-site hog barn operation within the Spirit Creek Watershed. This committee was chosen to collect non-biased information to determine potential effects from hog barn operations in their watershed.

The objective of this assessment was to report on and compare the quality of groundwater and surface water supplies within the watershed to *Saskatchewan's Municipal Drinking Water Quality Standards and Objectives*. Surface water runoff comparisons were made between upstream and downstream locations, including fields that received manure from hog barns and those that did not. Finally, an evaluation of Good Spirit Lake's water quality as compared to *Saskatchewan's Interim Surface Water Quality Objectives* was determined using the *Water Quality Index.*

Specific protocols were used for sampling wells, dugouts, surface water runoff and Good Spirit Lake. Sampling took place from the fall of 2000 to the spring of 2004, and was conducted by a sub-committee of the *Spirit Creek Watershed Monitoring Committee* and Saskatchewan Agriculture and Food. For wells and dugouts, parameters of interest included those which exceeded a health standard (*Maximum or Interim Acceptable Concentration*) or *Aesthetic Objective*. In the case of wells, provincial comparisons were made to information obtained through Saskatchewan Watershed Authority's *Rural Water Quality Advisory Program*. Paired data (spring to fall) for the years 2001 to 2003 was evaluated for wells and dugouts. Five wells of the 25 were paired; 22 of the 65 dugouts were paired.

On at least one occasion, at least one health standard (*Maximum Acceptable Concentration* or *Interim Maximum Acceptable Concentration*) was exceeded in 100% of the wells sampled. Parameters exceeding health standards for wells included: total and fecal coliform bacteria, nitrate and turbidity. Findings through the *Rural Water Quality Advisory Program* have shown that 50% of total wells sampled across the province exceed at least one health standard. Sixty-eight percent of wells in the Spirit Creek Watershed exceeded an *Aesthetic Objective* at least once compared to 93% of the wells tested through the *Rural Water Quality Advisory* Program. *Aesthetic Objectives* exceeded in wells within the Spirit Creek Watershed included: iron, magnesium, manganese, pH, sulphate, total alkalinity, total dissolved solids and total hardness. Typical of most shallow wells in Saskatchewan, wells in the Spirit Creek Watershed are not recommended for human consumption without treatment.

For all the dugouts, at least one health standard was exceeded during at least one sampling event. An *Aesthetic Objective* was exceeded at least once in 98.5% of the dugouts sampled. The health standards that exceeded in dugouts within the Spirit Creek Watershed were total and fecal

coliform bacteria and turbidity. *Aesthetic Objectives* exceeded in dugouts included: chloride, copper, iron, magnesium, manganese, pH, sodium, sulphate, total dissolved solids and total hardness. Dugout water quality is affected by many factors such as: inherent variability associated with precipitation and season, localized land-use and geology. For individual dugouts, year to year and spring to fall differences were not apparent due to natural variability of the parameters measured.

Analysis of surface water quality during spring runoff from 2001-2005 and a single grab sample from a storm event in 2005 suggests that the inter-annual variability of parameter concentrations was high. Although some of the key nutrients and microbiological indicators appeared to increase in concentration and some of the ionic constituents appeared to decrease in concentration during spring runoff from 2001/2002 to 2004/2005, concentrations from the 2005 storm sampling event did not follow this trend. Infrequent sampling (usually once a year) with no corresponding data on stream flow meant that it was impossible to draw meaningful conclusions about water quality in these streams. For example, during 2004 and 2005 higher concentrations of total ammonia nitrogen and total phosphorus were observed in the two areas with intensive livestock operations; however, the lack of a rigorous sampling design meant that there was no basis for assessing whether this difference was significant. It is suggested that using stable isotopes or microbial source tracking techniques may improve the sensitivity of detecting potential land-use impacts.

Water quality samples have been collected at Good Spirit Lake since 1998 by the Saskatchewan Watershed Authority and the *Friends of Good Spirit Lake Stewardship Group.* The *Water Quality Index* (score) was determined using *Saskatchewan's Interim Surface Water Quality Objectives* for each year sampled. In general, the *Water Quality Index* scores for Good Spirit Lake range from *Good* to *Excellent*, indicating little change over the past eight years. Parameters which regularly deviate (phosphorus and pH) from the *Interim Surface Water Quality Objectives* are likely influenced climate and natural cycles within the lake. Excursions or exceedances in chlorophyll *a*, dissolved oxygen, and fecal coliform bacteria and occur infrequently but do not indicate poor lake quality as they were not consistent.

In conclusion, Saskatchewan Watershed Authority suggests the following recommendations:

- Determine aquifer sensitivity as influenced by: depth, permeability, direction of groundwater flow and density of wells.
- An extensive description of site-specific land-use practices, their proximity to the sample site and well characteristics (i.e. age, depth, cribbing material, etc.) should accompany well and dugout water quality measurements. Protocol for this has been established by Saskatchewan Watershed Authority for the *Rural Water Quality Advisory Program*.
- Define land-use practices adjacent to surface water runoff sampling sites including recent and historical use. In addition, improve sampling methodology to facilitate the determination of total loading during spring runoff or storm events.
- Consider exploring new methods of source tracking for pollutant indicators (i.e. use of tracers such as nutrient isotopes and/or bacterial source tracking techniques).
- With naturally high (exceeding the *Saskatchewan Municipal Drinking Water Quality Standards*) levels of uranium occurring elsewhere in the province, it is advisable that the drinking water sources in the Spirit Creek Watershed be analyzed for this parameter.

1.0 INTRODUCTION

1.1 Background

In 2000, the *Friends of Good Spirit Lake Stewardship Group* hosted a meeting for both proponents and opponents of the hog operations to share their concerns and points of view. With three of the proposed barns located within the Upper Assiniboine River Basin, there were concerns with regard to the potential impact of these operations on water quality, soil condition, and air quality in the surrounding area. The *Spirit Creek Watershed Monitoring Committee* (SCWMC) was established in response to the approval of a multi-site hog barn operation within the Spirit Creek Watershed.

In response to local interest, an independent, non-biased committee was appointed by the Honourable Clay Serby, then Minister of Agriculture, Food and Rural Revitalization (later re-appointed by the Honourable Mark Wartman) to "…direct and communicate the monitoring of intensive hog development to ensure the sustainability of the environment in the Spirit Creek Watershed" (General meeting minutes Sept. 25, 2000). The resulting *Spirit Creek Watershed Monitoring Committee* (SCWMC) consisted of ten members representing the local community who were interested in collecting non-biased information to determine the presence or absence of hog barn influence on the environment. The committee established a mandate to monitor the water, soil, and air both before and after the introduction of the hog barns.

The multi-site hog project was to be operated by Big Sky Farms and was slated for development in 2000-2001. Beginning in the fall of 2000, water quality monitoring was led by committee member Ray Riesz and Chris Low of Saskatchewan Agriculture and Food. Samples were collected from wells, dugouts, and runoff sites within the Spirit Creek Watershed. Sampling continued until sufficient data was collected, ending in the spring of 2004.

In 2006, the Saskatchewan Watershed Authority's Water Quality Services unit was requested to report on the results from the water quality monitoring conducted by the SCWMC from 2000 to 2005. The objective of this assessment was to report on and compare the quality of the groundwater (wells) and surface water supplies (dugouts) to *Saskatchewan's Municipal Drinking Water Quality Standards and Objectives* (Saskatchewan Environment 2002). Runoff water quality was compared between upstream and downstream locations. Good Spirit Lake's water quality was compared to *Saskatchewan's Interim Surface Water Quality Objectives* (Saskatchewan Environment 2006) and the *Water Quality Index* score was calculated (Canadian Council of Ministers of the Environment 2001), was included in the water quality assessment because Good Spirit Lake is the receiving water body for the runoff in the watershed.

1.2 Study Objectives

The main purpose of the water quality monitoring study was to collect information on the ground and surface water quality within the Spirit Creek Watershed. Using this data, the SCWMC could improve sampling design for future monitoring of the effects of hog barn operations within the Spirit Creek watershed. From the data collected, the following objectives were accomplished:

1) assessment of well (or ground) water quality in the Spirit Creek Watershed determine the parameters which exceed *Saskatchewan's Municipal Drinking Water Quality Standards and Objectives* and compare percentage of wells exceeding to results from the Saskatchewan Watershed Authority's *Rural Water Quality Advisory Program*;
2) assessment of dugout (or surface) water quality in the Spirit Creek Watershed and determine the parameters which exceed *Saskatchewan's Drinking Water Quality Standards and Objectives*;
3) provide a synopsis and interpretation of water quality data collected during spring runoff in the Spirit Creek Watershed north of Good Spirit Lake over the past five years; and
4) report on the water quality of Good Spirit Lake.

Additionally, local resident participation was encouraged to increase awareness of local water quality and foster important relationships and communication links between the Saskatchewan provincial government, industry, local municipalities, and their constituents.

1.3 Study Area

Initially, both wells and dugouts were sampled within a three-mile radius of the three hog barns sites (Figure 1); however, by 2002 sampling was conducted within only a two-mile radius. A number of residents within the Spirit Creek Watershed rely on both private wells and dugouts for domestic use, drinking water, livestock watering, and various other uses.

Sampling sites for surface runoff were located in four sub-watersheds (referred to as Area 1, Area 2, Area 3, and Area 4), with Area 2 and 4 treated as controls. All of these sub-watersheds drain towards Good Spirit Lake (Figure 1).

Soil type throughout the watershed varies with geography. Prior to the placement of the hog barns, the soil type was determined in order to evaluate the risk associated with intensive livestock operations. Soil type around the barns and their operations consists of mostly clay till. Most of the monitored wells were located to the south-west of the barns and may be established in different soil types specific to their geographic location. Different geological characteristics make each well and dugout inclined to unique hydrology and water quality. Soils in the runoff study area are predominately loamy. The soils become loamy, sandy soils in the lower portion of Area 3 and the lower portion of all areas (closer to Good Spirit Lake).

Groundwater in the area consists of discontinuous water-bearing zones, including glacial aquifers which provide surficial shallow groundwater. Re-charge of groundwater reservoirs often varies with precipitation, surface runoff, and stream flow. In addition, the permeability of the soil influences groundwater movement or recharge. For example, clay formations have high water-holding potential but fail to be defined as an aquifer due to the tendency for water movement to be low (Johnson Division, Universal Oil Products Co. 1974).

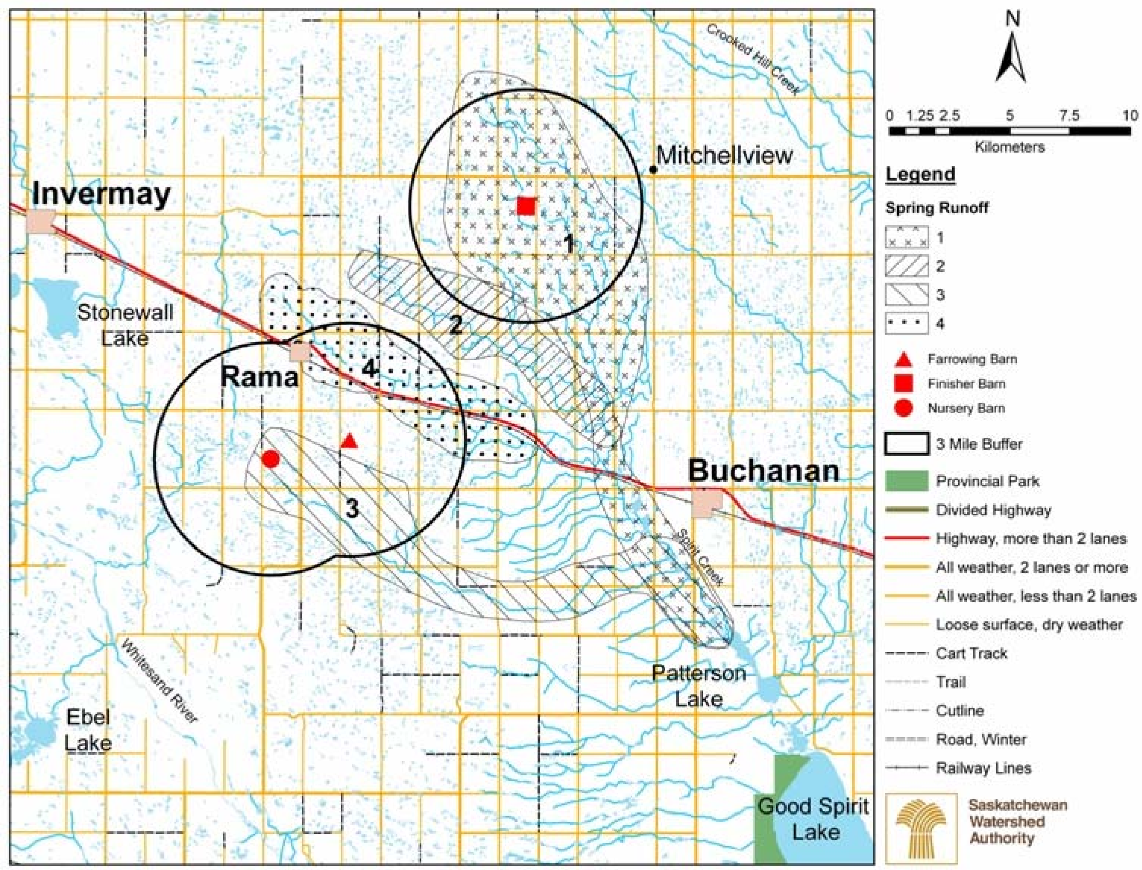

Figure 1 Study site and locations for water quality sampling within the Spirit Creek Watershed. Wells and dugouts are located within a three-mile radius around each barn (reduced to two-mile radius in 2002). Sub-watershed boundaries for runoff sampling occur in Areas 1, 2, 3, and 4. The locations of the hog barns are shown in red. Good Spirit Lake is located southeast of the barns.

Good Spirit Lake is a popular recreational lake located approximately 60 kilometers northwest of Yorkton, Saskatchewan. In addition to numerous villages, hamlets, and resort communities on the lake, Good Spirit Lake Provincial Park is located on the southwest side. It is a large lake with a surface area of approximately 44 km^2 and maximum depth of six meters. Inflow to the lake occurs via surface water runoff from Spirit Creek located at the north end, while outflow is controlled at the south end of the lake via a control structure.

From 2000 to 2004, the lake level of Good Spirit Lake fluctuated seasonally and showed a decline annually (Figure 2). Spring runoff and precipitation events temporarily increased lake levels, but as evaporation increased during the summer months, water levels decreased. Localized drought between 2000 and 2005 kept water levels below the control structure at the south end of the lake until the spring of 2006 when spring runoff and precipitation lead to the release of water from the structure.

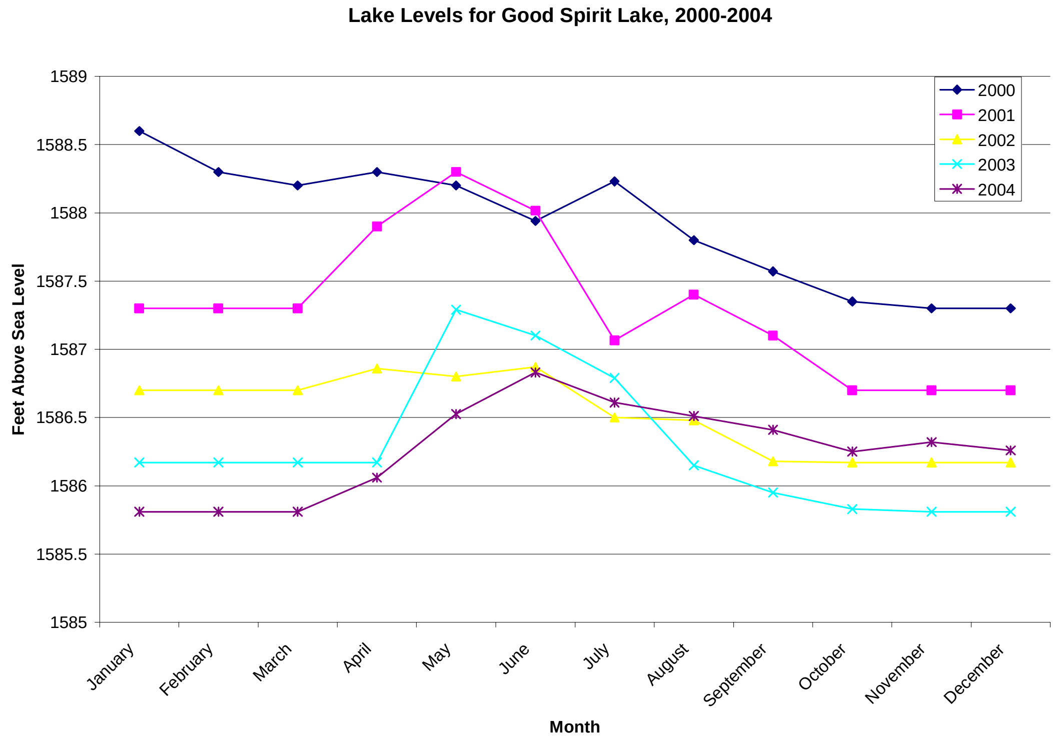

Figure 2 **Lake levels for Good Spirit Lake for each month from 2000 to 2004.**

1.4 Saskatchewan's Water Quality Standards and Objectives

Drinking Water

Based on the *Canadian Drinking Water Quality Guidelines* (Health Canada 1996), Saskatchewan has established *Municipal Drinking Water Standards and Objectives* for the province (Saskatchewan Environment 2002). Standards are "…legally enforceable requirements for drinking water quality…" and are set out in *The Water Quality Regulations* (2002) and the *Environmental Management and Protection Act* (2005) for the purpose of protecting human health. Standards must be diligently followed to ensure safe drinking water; therefore, failure to meet the standard means that the water must either be treated or not consumed by humans. Due to the heath risks associated with the exceedance of a standard, there is a *Maximum Acceptable Concentration* (MAC) set for the parameters of concern. When the MAC cannot be determined due to insufficient toxicological data, an *Interim Maximum Acceptable Concentration* (IMAC) is established.

Conversely, objectives are not mandatory; however, if exceeded they can deter human use by impeding supply systems or having non-aesthetic properties. Despite being of low risk to human health, the offensive nature of some parameters requires a guideline for acceptability, thus an *Aesthetic Objective*. Parameters with objectives can cause adverse health effects in some people if found in excessive concentrations.

Drinking water standards (mandatory) and objectives (guidelines) are applied to groundwater wells and surface water dugouts based on the possibility or assumption that people can access this water for domestic use, including consumption.

Surface Water

Surface water quality in the province is compared to the *Interim Saskatchewan Surface Water Quality Objectives* (Saskatchewan Environment 2006) which are based on the *Canadian Environmental Quality Guidelines* (Canadian Council of Ministers of the Environment 2002). The objectives for surface water quality are based on various uses including: protection of aquatic life, recreation and agriculture use.

1.5 The Rural Water Quality Advisory Program

The *Rural Water Quality Advisory Program* (RWQAP) is a voluntary water quality testing program provided by the Saskatchewan Watershed Authority that is available to anyone in the province relying on a private water source for their domestic water needs. The advisory program does not eliminate any wells from testing based on the type, age, or depth of the well; as a result, groundwater supplies have been tested from surficial, intertill, and bedrock aquifers. This provides information which is representative of a range of groundwater supplies that are being utilized as domestic water sources throughout the province. The RWQAP database currently includes over 3,000 water analyses.

1.6 The Water Quality Index

The *Water Quality Index* (WQI) is an effective means for summarizing a large number of water quality parameters. Similar to the UV index or an air quality index, it provides an indication of the overall water quality. The Saskatchewan Watershed Authority uses the WQI to report on lake water quality and educate the public as part of our *Lake Stewardship* and *Water Quality Monitoring*.

Values for various water quality parameters (e.g. dissolved oxygen, nutrients, fecal coliform) are compared to specific water quality objectives. The results of the comparisons are combined to provide a water quality ranking (e.g. *Good, Fair, Poor*) for individual water bodies. The advantages of an index include: its ability to represent measurements of many water quality parameters in a single number; its ability to combine numerous parameters with different measurement units; and its effectiveness as a communication tool. When the same objectives and variables are used, the index can be used to convey relative differences in water quality between sites and over time. The disadvantages of using the index include a loss of information on single variables, the sensitivity of the results to the formulation of the index, and the loss of information on interactions between variables.

The index is based on three components that relate to water quality objectives:

Scope - How many? - The number of water quality variables that do not meet objectives in at least one sample during the time period under consideration, relative to the total number of variables measured.

Frequency - How often? – The number of individual measurements that do not meet objectives, relative to the total number of measurements made in all samples for the time period of interest.
Amplitude - How much? - The amount by which measurements which do not meet objectives depart from those objectives.

WQI values range between 1 and 100. Once the WQI value has been calculated the value can be further simplified by assigning it to one of several descriptive categories:

Excellent: (WQI value 95-100) – Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time.
Good: (WQI value 80-94) – Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair: (WQI value 60-79) – Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal: (WQI value 45-59) – Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor: (WQI value 0-44) – Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

2.0 METHODS

A sub-committee of the SCWMC was established to collect water quality samples, have them analyzed, and communicate the results to the larger group and to the public. With the assistance of Saskatchewan Agriculture and Food, the group established their experimental design, including the sampling methodology and data collection. All sampling took place from the fall of 2000 to the spring of 2004.

Samples taken by the SCWMC were analyzed for general chemistry and bacteria by the Provincial Laboratory in Regina with select duplicate samples analyzed by the Saskatchewan Research Council in Saskatoon. More than 30 parameters were analyzed, including major ions, metals, general water chemistry, and bacteria (Table 1). Finally, the data that was collected was transferred to the Saskatchewan Watershed Authority for data analysis, interpretation and recommendations.

Table 1 Parameters tested for Spirit Creek monitoring of water quality.

Groundwater	Surface Water	Surface Water Runoff	Lake Water Quality	
Aluminium	Aluminium	Aluminium	2,4-Dichlorophenol	Total Coliform Bacteria
Arsenic	Bicarbonate	Arsenic	2-Methyl-4-Chlorophenoxyacetic acid	Total Dissolved Solids
Barium	Biological Oxygen Demand	Barium	Aluminium	Total Hardness
Bicarbonate	Calcium	Bicarbonate	Arsenic	Total Kjeldahl Nitrogen
Biological Oxygen Demand	Chloride	Biological Oxygen Demand	Bicarbonate	Total Phosphorus
Boron	Chlorophyll *a*	Boron	Biochemical Oxygen Demand	Turbidity
Calcium	Conductivity	Calcium	Calcium	
Chloride	Copper	Chloride	Carbonate	
Conductivity	Dissolved Organic Carbon	Chlorophyll *a*	Chemical Oxygen Demand	
Copper	Fecal Coliform Bacteria	Conductivity	Chloride	
Dissolved Organic Carbon	Fecal Strep	Copper	Chlorophyll *a*	
Fecal Coliform Bacteria	Heterotrophic Plate Count	Dissolved Organic Carbon	Chromium	
Fecal Strep	Iron	Fecal Coliform Bacteria	Conductivity	
Heterotrophic Plate Count	Magnesium	Fecal Strep	Dissolved Organic Carbon	
Iron	Manganese	Heterotrophic Plate Count	Dissolved Oxygen	
Lead	Nitrogen	Iron	Fecal Coliform Bacteria	
Magnesium	Nitrogen (nitrate & nitrite)	Lead	Fecal Strep	
Manganese	Nitrogen (total ammonia)	Magnesium	Iron	
Nitrogen (Total Ammonia)	pH	Manganese	Magnesium	
Nitrogen (Total)	Phosphate (Ortho)	Nitrogen (Nitrate)	Manganese	
pH	Total Phosphorus	Nitrogen (Total Ammonia)	Mercury	
Phosphate (Ortho)	Potassium	pH	Nitrogen (Nitrate and Nitrite)	
Total Phosphorus	Selenium	Phosphate (Ortho)	Nitrogen (Nitrate)	
Potassium	Sodium	Total Phosphorus	Nitrogen (Total Ammonia)	
Selenium	Sulphate	Potassium	pH	
Sodium	Total Alkalinity	Selenium	Phenol Alkalinity	
Sulphate	Total Coliform Bacteria	Sodium	Phosphate (Ortho)	
Total Alkalinity	Total Dissolved Solids	Sulphate	Potassium	
Total Coliform Bacteria	Total Hardness	Total Alkalinity	Preserved Mercury	
Total Dissolved Solids	Total Kjeldahl Nitrogen	Total Coliform Bacteria	Sodium	
Total Hardness	Turbidity	Total Dissolved Solids	Sulphate	
Total Kjeldahl Nitrogen		Total Hardness	Suspended (Total)	
Turbidity		Total Kjeldahl Nitrogen	Suspended Solids (Fixed)	
Zinc		Turbidity	Suspended Solids (Volatile)	
		Zinc	Total Alkalinity	

2.1 Wells & Dugout Water Sampling and Data Analysis

Initial well and dugout sampling took place in fall of 2000 within a three-mile radius of each of the three barns (the farrow, nursery, and finisher barns); however, the sampling effort was decreased to a two-mile radius in 2002. In addition, reservoirs supplying water to Rama and Buchanan were sampled as they are catchments within the watershed. Both reservoirs are included in the data analysis for surface water dugouts.

Specific protocols were used for the sampling of wells, dugouts, surface water runoff, and Good Spirit Lake. Well sampling was conducted in accordance with standard sampling protocol and included purging and stabilizing the well prior to the collection of a grab sample. All water samples were collected as close to the well head as possible, before any storage facilities such as a cistern or any treatment equipment. Taps or hydrants were disinfected with bleach. Site-specific information, including well depth, physical well characteristics, and local land-use practices were not collected; however, informal observations indicate that wells were all shallow with a total depth of less than 30 m. Surface water including dugouts, surface water runoff and Good Spirit Lake were also sampled following standard protocols for grab samples. Dugouts with repeat samples were consistently sampled at the same depth and location. Lake sampling was initiated by Sask Water from 1998-2002 and continued by Saskatchewan Watershed Authority staff to present. Samples were filtered in the field, preserved and shipped on ice.

For parameters with exceedances of standards/objectives, and/or provincial comparison, descriptive statistics including the mean, standard deviation, median and range values were determined. The standard deviation is a measure of data predictability and distance from the mean. Increased standard deviation indicates the data is less predictable or more variable. After data has been arranged from lowest to highest, the number splitting the data in half is called the median. The range describes the minimum and maximum values in the data set. Unlike the mean, the median is less sensitive to extreme values. Descriptive statistics for all parameters tested are referenced in Appendix A.

Box plots were used to visually interpret the results. They summarize the range of data, where the lower edge of the box represents the 25th percentile, and the upper edge of the box represents the 75th percentile. The horizontal line in the middle of the box shows the median value (middle value) of the data range. Because the number of samples was limited, the traditional ‘whiskers’ on the box plots were not present. Box plots for parameters exceeding standards/objectives are referenced in Appendix B.

Exceedances were ascertained by comparing water quality results from wells and dugouts to the *Municipal Drinking Water Quality Standards and Objectives* for Saskatchewan (Saskatchewan Environment 2002). Parameters and the percentage of wells or dugouts with exceedances were determined for the sampling period from 2000 to 2004. Some wells and dugouts were sampled multiple times. Only one sample per individual well or dugout (taken at any time) was needed to qualify a parameter as an exceedance. For example, if well x was sampled six times during the study but exceeded nitrates in only one sample, well x would count towards the total percentage of wells exceeding for nitrates. For wells with parameters that exceeded a standard or objective, a comparison was made with data provided by the Saskatchewan Watershed Authority's *Rural Water Quality Advisory Program.*

Parameters that exceeded a *Municipal Drinking Water Standard or Objective* in the larger data set (25 wells or 65 dugouts) were graphically represented using paired data only (5 wells and 22 dugouts). From year to year as well as spring to fall, data was evaluated for changes in water quality by parameter (Appendix C).

2.2 Surface Water Runoff Sampling and Data Analysis

Spring and storm-event surface water quality sampling in the Spirit Creek watershed has been conducted since 2001. Sampling involved collecting a single grab sample sometime during spring runoff. In 2005, an additional grab sample was taken in June after a storm event.

Sampling sites are located in four sub-watersheds (referred to as Area 1, Area 2, Area 3 and Area 4). All of these sub-watersheds drain toward Good Spirit Lake (Figure 1). Data was summarized parameter-by-parameter in two sets of graphs. The first graphs are box plots (Appendix D). The second sets of graphs are line graphs and they show the concentrations at various points along the streams, thus providing a means of assessing spatial variability (Appendix E).

2.3 Good Spirit Lake Water Quality Sampling and Data Analysis

Since 1998, collection of all field measurements and water sampling at Good Spirit Lake has been facilitated by Saskatchewan Watershed Authority personnel, with the participation of the *Friends of Good Spirit Lake Stewardship Group*. Water samples are taken four to six times per year at a baseline station (established in 1997) in the centre of the lake.

Sampling measurements taken in the field include pH, turbidity, conductivity, and dissolved oxygen. Laboratory analysis included tests for nutrients, major ions, chlorophyll *a*, dissolved and suspended solids and bacteria. Sampling for metals and pesticides was initiated in 2003. Sample analysis is conducted by the Provincial Laboratory and the Saskatchewan Research Council. The complete methodology for lake monitoring can be referenced in the Saskatchewan Watershed Authority's *Good Spirit Lake Water Quality Report for 2003-2004* (2005).

The *Water Quality Index* (WQI) score was determined for each year that Good Spirit Lake was sampled. All available and pertinent parameters were entered into the WQI and calculated using the *Interim Surface Water Quality Objectives*. The 16 parameters and their objectives can be referenced in Appendix F.

3.0 RESULTS AND DISCUSSION

3.1 Water Sampling of Wells

In total, 25 wells were sampled within the Spirit Creek Watershed. A different number of wells were sampled in each year of the study. For the period 2000 to 2004, the total number of wells sampled annually were n=11, n=25, n=24 n=10 and n=9, respectively. Paired seasonal sampling between spring and fall occurred from 2001 to 2003, with five wells having paired seasonal data for all three years.

Groundwater sampling tested for 34 of which 13 of these parameters exceeded the *Municipal Drinking Water Quality Standards and Objectives* in one or more of the wells (Table 2). Parameters exceeding health standards include: total coliform bacteria, fecal coliform bacteria, nitrates, and turbidity. The *Aesthetic Objectives* exceeded included: iron, magnesium, manganese, pH, sulphate, total alkalinity, total dissolved solids, and total hardness. None of the wells exceeded standards for arsenic, barium, boron, lead, selenium, and copper or objectives for chloride, sodium, and zinc. Saskatchewan Watershed Authority's suggested objective of <5 mg/L for dissolved organic carbon was also exceeded in more than one well.

The mean, standard deviation, median and range were determined for each drinking water parameter (Table 2). Descriptive statistics for parameters tested for which there was no standard or objective and/or provincial comparison to the *Rural Water Quality Advisory Program* are referenced in the Appendix A. Data were considerably variable, indicating just how variable well water quality is between individual wells and annually/seasonally within one well (Appendix B).

A health standard, defined by the *Maximum Acceptable Concentration or Interim Maximum Acceptable Concentration*, was exceeded in 100% of the wells at least once. An *Aesthetic Objective* was exceeded at least once in 68% of the wells sampled. In comparison, the percentage of health standards exceeded in wells tested through the *Rural Water Quality Advisory Program* throughout the province was 50% while *Aesthetic Objectives* are exceeded in 93% of the wells sampled. In the Spirit Creek Watershed, wells sampled exceeded health standards twice as much as the provincial percentage while exceeding *Aesthetic Objectives* 25% less than wells sampled throughout the province.

Dissolved Organic Carbon

Dissolved Organic Carbon (DOC) is a measure of the organic material dissolved in water. Organic matter in water can cause several aesthetic problems such as unpleasant taste, odour and colour. Organics can interfere with the efficiency of water treatment equipment, promote bacterial growth in pipes and generate harmful chlorinated organic compounds in chlorinated water. Although no provincial guideline for dissolved organics has been set, it is recommended by the Saskatchewan Watershed Authority that levels be below 5 mg/L to help minimize the problems associated with these compounds.

Table 2 Descriptive statistics for parameters tested with provincial Municipal Drinking Water Quality Standards and Objectives in wells.

Parameter	Total Sample #	Drinking water standard/objective	Objective Type	Mean	Standard Deviation	Median	Range (min -max)
DOC	116	5 mg/L	SWA*	7.207	±4.506	6.0	0 - 24
Arsenic	85	25 µg/L	IMAC	4.40×10^{-4}	±0.001	0.0	0 - 0.009
Barium	111	1 mg/L	MAC	0.095	±0.099	0.1	0.009 - 1
Boron	81	5 mg/L	IMAC	0.000	±0.000	0.0	0 - 0
Fecal Coliform Bacteria	108	0 ct/100mL	MAC	10.157	±64.864	0.0	0 - 520
Lead	84	0.01 mg/L	MAC	0.000	±0.001	0.0	0 - 0.006
Nitrate	108	45 mg/L	MAC	32.033	±59.469	14.5	0 - 428
Selenium	90	0.01 mg/L	MAC	5.80×10^{-4}	±0.001	0.0	0 - 0.005
Total Coliform Bacteria	109	0 ct/100mL	MAC	35.899	±111.279	0.0	0 - 610
Turbidity	114	1 NTU	MAC	10.109	±44.707	0.5	0 - 412
Chloride	116	250 mg/L	AO	12.379	±29.681	3.5	0 - 196
Copper	87	1 mg/L	AO	0.013	±0.040	0.0	0 - 0.2
Iron	95	0.3 mg/L	AO	1.082	±4.340	0.0	0 - 34.7
Magnesium	116	200 mg/L	AO	77.750	±50.542	67.0	19 - 351
Manganese	101	0.05 mg/L	AO	0.320	±1.034	0.0	0 - 8
pH	116	6.5-9.0 pH units	AO	7.512	±0.346	7.5	6.7 - 10
Sodium	116	300 mg/L	AO	18.164	±20.866	14.5	2 - 134
Sulphate	116	500 mg/L	AO	243.216	±237.945	185.5	0 - 1563
Total Alkalinity	116	500 mg/L	AO	339.690	±113.124	316.0	148 - 764
TDS	116	1500 mg/L	AO	916.638	±434.697	866.0	326 - 2893
Total Hardness	116	800 mg/L	AO	602.362	±292.679	581.5	194 - 1,915
Zinc	83	5 mg/L	AO	0.1082	±0.703	0.0	0 - 4

*The Saskatchewan Watershed Authority recommends the objective of <5 mg/L for dissolved organic carbon. Shaded parameters indicate exceedances in at least one well.

Of the 25 wells tested, 68% had DOC levels higher than 5 mg/L in at least one sample (Figure 3). Sample values ranged from zero to 24 mg/L, with a mean value of 7.2 (SD±4.506) mg/L and a median of 6.0 mg/L (Table 2). In comparison, the percentage of wells in the *Rural Water Quality Advisory Program* that exceeded the Saskatchewan Watershed Authority's suggested objective was 47% for all wells tested and 47% for shallow wells less than 30 meters in depth. Given the lack of information regarding land-use and well characteristics such as age and depth, it is difficult to determine the reason for the greater percent of wells exceeding 5 mg/L of DOC in the Spirit Creek Watershed. Also worth noting is the sample size of 25 wells in the Spirit Creek Watershed, in comparison to the greater than 3,000 wells sampled through the *Rural Water Quality Advisory Program*.

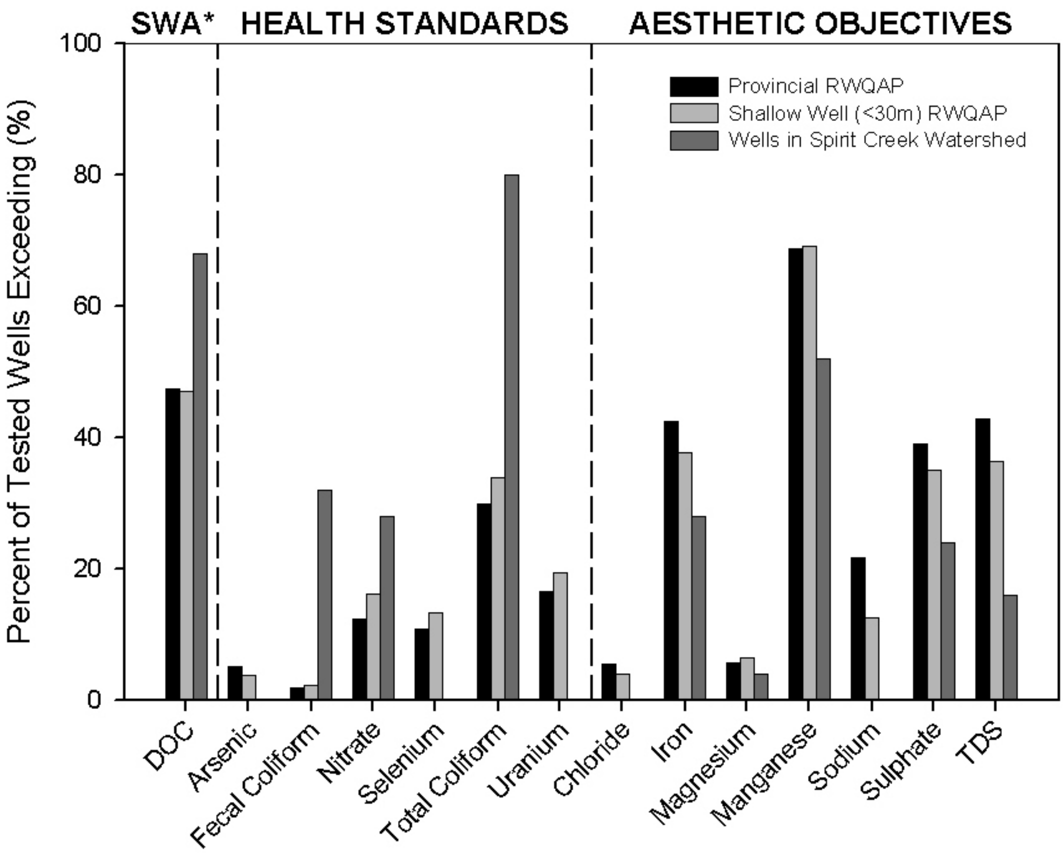

Figure 3 Percentage of wells sampled in the Spirit Creek Watershed that exceeded standards and objectives in comparison to the Rural Water Quality Advisory Program. Dissolved organic carbon is included by the Saskatchewan Watershed Authority, though no Maximum Acceptable Concentration has been determined.

Total and Fecal Coliform Bacteria

The presence of total coliform bacteria does not necessarily mean disease-causing organisms exist in the water; however, it can indicate the current or potential risk of disease-causing pathogens. The test is used as an indicator of the bacteriological quality of the water as related to the possible presence of disease-causing organisms. As total coliform bacteria are a health-related parameter, the *Maximum Acceptable Concentration* is zero organisms detectable per 100 mL of water (Saskatchewan Environment 2002).

Of the 25 wells tested, total coliform bacteria had the highest percentage of exceedances with 80% of the wells containing total coliform bacteria higher than zero organisms per 100 mL at least once (Figure 3). Values ranged from counts of zero to 610 ct/100mL, with a mean of 35.9 (SD±111.279) ct/100mL and a median of 0.0 ct/100mL (Table 2). In comparison, the percentage of wells in the *Rural Water Quality Advisory Program* that exceeded the *Maximum Acceptable Concentration* was 30% for all wells tested in the province and 34% for shallow wells less than 30 metres in depth.

Contained within the total coliform group of organisms is a sub-group known as fecal coliform bacteria. These are typically found in the intestines of warm-blooded animals. If fecal coliform bacteria are detected in drinking water, contamination by sewage or other sources of fecal matter may be a possible cause. The *Maximum Acceptable Concentration* for fecal coliform bacteria is zero organisms detectable per 100 mL of water (Saskatchewan Environment 2002).

Fecal coliform bacteria were detected in 32% of the wells tested, with levels ranging from zero to 520 ct/100mL at least once (Figure 3). The mean count for fecal coliform bacteria was 10.2 (SD±64.864), with a median of 0.0 ct/100mL (Table 2). In comparison to the *Rural Water Quality Advisory Program*, fecal coliform bacteria detected in the Spirit Creek Watershed were higher than the provincial percentage of 2% for all wells and 2 % for shallow wells.

A survey completed in Alberta showed that 14% of wells tested had total coliform bacteria present, while 6% had fecal coliform bacteria (Canada-Alberta Environmentally Sustainable Agriculture 1998). In the Spirit Creek Watershed, fecal coliform bacteria counts were higher than the levels reported for the province as a whole. The lack of site-specific land-use information for each individual well makes it impossible to determine the cause of coliform contamination. Localized activities within the immediate farmyard likely influence coliform levels in wells, thus reinforcing the need for individual proper water treatment and well maintenance.

Nitrate

Nitrate is a health-related parameter, and water supplies with nitrate exceeding provincial standards should not be consumed without rectifying the source of the problem or installing treatment. The presence of nitrate in water could indicate contamination resulting from decaying plant or animal material, agricultural fertilizers, manure, or domestic waste. Though nitrates are found naturally in some wells, levels are usually quite low. Wooden well cribbing itself can be a source of nitrate as it decomposes. As nitrate is soluble it is highly mobile in soil and can readily migrate to the water table. Wells should be thoroughly inspected for possible sources of contamination (i.e. runoff) and should then be monitored to detect any increase in the level of nitrate over time. The *Maximum Acceptable Concentration* for nitrate is 45 mg/L (Saskatchewan Environment 2002).

Of the 25 wells tested with detectable nirate, 28% exceeded the provincial standard for nitrate at least once (Figure 3). The nitrate concentrations ranged from zero to 428 mg/L. In comparison, the percentage of wells in the *Rural Water Quality Advisory Program* that exceeded the provincial MAC for nitrate was 12% for all wells tested and 16% for shallow wells less than 30 metres deep.

Of the wells tested in the Spirit Creek Watershed, the mean level of nitrate was 32.0 (SD±59.469) mg/L, with a median of 14.5 mg/L (Table 2). Mean and median for shallow wells in the *Rural Water Quality Advisory Program* are 28.6 mg/L and 2.4 mg/L, respectively. The mean level for nitrates in provincial shallow wells is similar to the mean level of nitrates in the wells sampled in the Spirit Creek Watershed; therefore levels of nitrate are not unexpected. The high standard deviation and large range indicated high variability. This means that there were a few wells with extreme levels of nitrate. The lack of individual well information makes it impossible to determine the direct cause of exceeding nitrate values.

Maathuis (2000) conducted a review of several groundwater quality surveys in Saskatchewan and found that the percentage of wells that exceeded the MAC for nitrate ranged from 7 to 42%. This variation was accounted for based on the area of the survey, the number of wells sampled and the depth of the wells tested. Shallow wells were shown to have a higher level of nitrate contamination. Similarly, water quality surveys in other jurisdictions across Canada have also reported elevation of 13% to 14% in nitrate in domestic wells (Canada-Alberta Environmentally Sustainable Agriculture 1998; Gross et al. 1998).

Turbidity

Turbidity is a measure of water clarity. Turbidity is caused by solids suspended in the water, possibly including clay, silt or biological organisms. Increased turbidity can affect both the health and the aesthetic properties of water. Suspended particles can decrease the efficiency of water treatment by providing water-borne organisms with a source of nutrients and surface area on which to grow. In addition, due to their adsorptive properties, suspended particles can accumulate to higher concentrations of heavy metal ions and biocides. The *Maximum Acceptable Concentration* for turbidity is 1 nephelometric turbidity unit (NTU) (Health Canada 1996).

Turbidity was exceeded in 64% of the wells sampled in the Spirit Creek Watershed. Values for turbidity ranged from zero to 412 NTU, with a mean of 10.1 (SD±44.707) NTU and median of 0.5 NTU. It cannot be determined at this time if increased turbidity contributes to increased total coliforms or vice-versa; however, 48% of the wells tested exceeded in both total coliform bacteria and turbidity.

Arsenic, Selenium, and Uranium

Arsenic is naturally released into the environment by rock weathering and is therefore naturally present in some groundwater supplies. However, arsenic is used in many industrial processes and products including pesticides and herbicides. Arsenic ranged from zero to 0.009 µg/L, with a mean of 4.40×10^{-4} (SD±0.001) and median of 0.0 µg/L (Table 2). Provincially, within the *Rural Water Quality Advisory Program* 5% of all wells sampled exceeded the standard of 25 µg/L (Saskatchewan Environment 2002), whereas only 4% of shallow wells exceeded the provincial standard. The wells sampled in the Spirit Creek Watershed had 0% exceedances for arsenic (Figure 3).

Of the 25 wells sampled, selenium values ranged from zero to 0.005 mg/L, with a mean of 5.80×10^{-4} (SD±0.001) and median of 0.0 mg/L (Table 2). Among all wells tested in the province under the *Rural Water Quality Advisory Program*, 11% exceeded the provincial selenium standard, with an increased proportion for shallow wells of 13%. Wells sampled in the Spirit Creek Watershed had 0% exceedances for selenium (Figure 3).

Uranium is found as either a naturally occurring element or as a result of human activities (i.e. uranium mill tailings and phosphate fertilizers). High levels of uranium in drinking water can affect the kidneys; however, exposure to variable levels of uranium over time has not conclusively been shown to have the same effects. The standard for the MAC for uranium is 20 mg/L, of which 16% of the wells sampled through the *Rural Water Quality Advisory Program* exceed. The percentage of shallow wells in the *Rural Water Quality Advisory Program* exceeding the standard for uranium is 20%. None of the wells sampled in the Spirit Creek Watershed were tested for uranium. Given the percentage of wells that exceeded the uranium standard provincially, it would be suggested that future well testing include uranium.

Iron

Iron has an *Aesthetic Objective* of 0.3 mg/L (Saskatchewan Environment 2002). Groundwater contains variable amounts of iron depending on the geology of the area and other chemical components of the aquifer. Iron in water supplies used for domestic purposes tends to stain laundry and plumbing fixtures while causing an undesirable taste. When iron precipitates, it causes a reddish-brown colour in the water as it combines with the tannins in tea or coffee. Water that is high in iron favours the growth of iron bacteria, a slime-forming organism whose growth can cause clogging of pipes and foul tastes and odour. In water treatment, high iron levels can interfere with treatment processes by fouling membranes and water softeners.

Of the 25 wells sampled, 28% exceed the objective of 0.3 mg/L at least once (Figure 3). Values for iron in the Spirit Creek Watershed ranged from zero to 34.7 mg/L, with a mean of 1.1 (SD±4.340) mg/L and median of 0.0 mg/L (Table 2). Provincially, 43% of wells tested through the *Rural Water Quality Advisory Program* exceeded the iron objective, with 38% of shallow wells exceeding the objective of 0.3 mg/L. Local geology is most likely the largest contributor to the lower percentage of wells exceeding in the Spirit Creek Watershed.

Magnesium

Magnesium is present in all natural waters. A high level of magnesium in groundwater is probably a result of the water coming into contact with rock formations containing magnesium. Magnesium is a major contributor to water hardness and may also contribute to undesirable taste in drinking water. When present in water containing sulphate, magnesium may have a laxative effect or cause gastrointestinal irritation. The *Aesthetic Objective* for magnesium is 200 mg/L (Saskatchewan Environment 2002).

Magnesium exceeded at least once in 4% (Figure 3) of the 25 wells sampled in the Spirit Creek Watershed. Values for magnesium ranged from 19 mg/L to 351 mg/L with a mean of 77.8 (SD±50.542) and median of 67.0 mg/L (Table 2). Both total wells and shallow wells sampled in the province through the *Rural Water Quality Advisory Program* each showed a 6% exceedance of the objective for magnesium. The percentage of wells exceeding the objective of 200 mg/L is lower than the provincial proportion and most likely reflects the local geology.

Manganese

Manganese represents another aesthetic concern for groundwater supplies in the province. Manganese salts and minerals are widely distributed in rock, soil, and sediments. Although iron and manganese are usually found together in groundwater supplies, manganese in Saskatchewan has been shown to exceed *Aesthetic Objectives* more frequently than iron (Sketchell and Shaheen 1999). Presence of manganese can cause water to have an objectionable taste or odour and produce dark brown or black stains on plumbing fixtures and laundry. Deposits in plumbing fixtures will frequently contain black sediment and cause turbidity. Dissolved manganese oxidizes more slowly than iron and is more difficult to remove from water. The *Aesthetic Objective* for manganese is 0.05 mg/L (Saskatchewan Environment 2002).

Fifty-two percent of the 25 wells sampled in the Spirit Creek Watershed exceeded the objective for manganese at least once (Figure 3). Values of manganese in the area ranged from zero to 8 mg/L, with a mean of 0.3 (SD±1.034) and median 0.0 mg/L. (Table 2) In comparison to the *Rural Water Quality Advisory Program*, manganese in the Spirit Creek Watershed is lower than that of all provincial wells sampled (69%) or, exclusively, shallow wells (69%). In a review of groundwater surveys, Maathuis (2000) found that the percent of wells in the province that exceeded the *Aesthetic Objective* ranged from 59% to 84%. The percentage of wells exceeding in manganese for the Spirit Creek Watershed appears to fall below the above-noted range for the province.

pH

Maintaining appropriate pH levels in water used for domestic purposes can minimize corrosion and scaling, which can become excessive when combined with other parameters (i.e. total dissolved solids, hardness, and alkalinity). The interaction of pH and other parameters can cause considerable damage to water supply systems. Corrosion becomes a significant problem when pH drops below 6.5 (acidic); however, scaling becomes an issue with pH values above 8.5 (basic). The acceptable range for pH in drinking water is from 6.5-8.5 (Saskatchewan Environment 2002).

Of the 25 wells sampled in the Spirit Creek Watershed, 4% exceeded the objective for pH at least once. Values for pH ranged from 6.7 to 10, with a mean value of 7.5 (SD±0.346) and median of 7.5. A function of the local geology, pH values are variable between wells but are relatively stable over time within any one particular well.

Sulphate

Sulphates occur naturally in numerous minerals and are used in the manufacture of chemical fertilizers and in sewage treatment. Sulphate is one of the least toxic anions; however, excessive ingestion can cause gastrointestinal irritation, particularly in small children and new users. In addition, high sulphate can result in an undesirable taste in drinking water, and thus reduces the aesthetic quality of water intended for consumption. The *Aesthetic Objective* for sulphate in drinking water is 500 mg/L (Saskatchewan Environment 2002).

Of the 25 wells sampled, 24% exceeded the objective for sulphate in drinking water at least once (Figure 3). The range of values for sulphate was zero to 1563 mg/L, with a mean of 243.2 (SD±237.945) and median of 185.5 mg/L (Table 2). In comparison, 39% of all wells sampled through the *Rural Water Quality Advisory Program* had sulphate levels above the *Aesthetic Objective* of which 35% of shallow wells exceeded.

Total Alkalinity

Total alkalinity is a measure of the water's ability to neutralize acid and is a function of carbonate, bicarbonate and hydroxide content. In groundwater it is influenced by both the atmosphere and the soil. Excessive total alkalinity in the water supply can produce a "soda" taste and has a drying effect on the skin when used for bathing or washing. Hard water with high alkalinity will readily precipitate, causing scale build up in water heaters. The *Aesthetic Objective* for alkalinity is 500 mg/L (Saskatchewan Environment 2002).

Twenty percent of the 25 wells sampled in the Spirit Creek Watershed exceeded the objective for total alkalinity at least once (Figure 3). Alkalinity values ranged from 148 mg/L to 764 mg/L, with a mean of 339.7 (SD±113.124) and median of 316.0 mg/L (Table 2).

Total Dissolved Solids

Total dissolved solids (TDS) refer mainly to the inorganic substances that are dissolved in the water. The main ions contributing to the sum of total ions (TDS) include the cations (calcium, magnesium, sodium, and potassium) and their anions (bicarbonate, sulphate, and chloride). The effects of TDS on drinking water quality (hardness, taste, mineral deposition and corrosion) depend on the levels of its individual components. Low levels of TDS contribute to the palatability of water. Specific conductivity is a useful measurement to estimate the concentration of TDS in the water. The *Aesthetic Objectives* for TDS in drinking water is less than 1,500 mg/L (Saskatchewan Environment 2002).

Of the 25 wells sampled in the Spirit Creek Watershed, 16% exceeded the provincial objective of 1,500 mg/L for total dissolved solids at least once (Figure 3). Values for TDS ranged from 326 mg/L to 2893 mg/L, with a mean of 916.6 (SD±434.697) mg/L and median of 866.0 mg/L (Table 2). In comparison, 43% of total wells sampled and 36% of shallow wells sampled through the *Rural Water Quality Advisory Program* in the province exceed the objective. In the review of water quality databases in Saskatchewan, Maathuis (2000) found that the percentage of wells exceeding the TDS objective range from 33% to 71% of the wells sampled. The proportion of wells in the Spirit Creek Watershed exceeding in TDS is lower than the above-noted provincial range.

Total Hardness

Total hardness is largely due to the presence of calcium and magnesium in the water. Scale formation and excessive domestic use of soap cause concerns when using hard water. Water hardness forms soap curds which adhere to cloth fibers, hair, glassware, and dishes resulting in ineffective cleaning/laundering. When hard water is heated, it has a tendency to form scale deposits. The *Aesthetic Objective* for total hardness is 800 mg/L (Saskatchewan Environment 2002).

Of all aesthetic parameters, total hardness most often exceeded with 40% of the 25 wells sampled exceeding at least once (Figure 3). Total hardness values ranged from 194 mg/L to 1,915 mg/L, with a mean of 602.4 (SD±292.679) and median of 581.5 mg/L (Table 2). Hard water is not atypical of Saskatchewan groundwater.

Sodium and Chloride

Sodium is a cation (positively charged ion) found in all natural sources of water or in water supplies softened through ion exchange. High concentrations of sodium tend to increase the corrosive effect of the water and decrease palatability. For health reasons, sodium rich water (including softened water) should not be consumed. The *Aesthetic Objective* for sodium is 300 mg/L (Saskatchewan Environment 2002). Provincially, 22% of wells exceed the objective for sodium, with 13% of shallow wells exceeding 300 mg/L. None of the 25 wells tested in the Spirit Creek Watershed exceeded the objective for sodium (Figure 3).

Chloride is an anion (negatively charged ion) commonly found in groundwater as a result of soil type. The presence of chloride can impart an undesirable taste to the water. Though there is no evidence that chloride ingestion is harmful, the *Aesthetic Objective* for chloride in drinking water is 250 mg/L (Saskatchewan Environment 2002). Provincially, 6% of wells tested through the *Rural Water Quality Advisory* Program exceeded the objective for chloride, with 4% of shallow wells exceeding 250 mg/L. None of the 25 wells tested in the Spirit Creek Watershed exceeded the objective for chloride (Figure 3).

3.2 Water Sampling of Dugouts

In total, 65 dugouts were sampled within the Spirit Creek Watershed. A different number of dugouts were sampled in each year of the study. For the period from 2000 to 2004, the numbers of dugouts sampled were n=37, n=61, n=59, n=25 and n=25, respectively. Paired seasonal sampling between spring and fall occurred from 2001 to 2003, with 22 dugouts having paired seasonal data for all three years.

Water sampling included 31 parameters, with a total of 15 parameters exceeded at least once in one or more of the dugouts (Table 3). Parameters exceeding health standards from *Saskatchewan's Municipal Drinking Water Quality Standards and Objectives* (Saskatchewan Environment 2002) included: fecal coliform bacteria, heterotrophic plate count, total coliform bacteria, and turbidity. The *Aesthetic Objectives* exceeded include chloride, copper, iron, magnesium, manganese, pH, sodium, sulphate and total dissolved solids. None of the dugouts exceeded objectives for nitrate, selenium or total alkalinity. The Saskatchewan Watershed Authority's suggested objective of <5 mg/L for dissolved organic carbon was exceeded in more than one dugout.

The average, standard deviation, median and range were determined for each drinking water parameter (Table 3). Descriptive statistics for parameters tested for which there was no standard or objective applied are referenced in the Appendix A. Paired dugout data from year to year and between spring and fall is variable (Appendix B).

At least one health standard was exceeded in 100% of the dugouts. The *Aesthetic Objectives* were exceeded at least once in 98.5% of the dugouts sampled.

Table 3 Descriptive statistics for parameters tested in dugouts to which provincial Drinking Water Standards and Objectives apply. Shaded parameters exceeded in at least one dugout.

Parameter	Total Sample Number	Drinking Water Standard/Objective	Objective Type	Mean	Standard Deviation	Median	Range (min to max)
Dissolved Organic Carbon	317	<5 mg/L	SWA*	18.054	±7.696	17	0 - 56
Fecal Coliform Bacteria	284	0 ct/100mL	MAC	16.563	±162.437	0	0 - 2690
Nitrate	291	45 mg/L	MAC	0.777	±2.893	0	0 - 36
Selenium	223	0.01 mg/L	MAC	0.000	±0.000	0	0 - 0.002
Total Coliform Bacteria	282	0 ct/100mL	MAC	250.567	±999.224	35	0 - 13000
Turbidity	317	1 NTU	MAC	5.664	±6.638	3.66	0 - 68.7
Chloride	317	250 mg/L	AO	5.423	±15.647	2	0 - 254
Copper	224	1 mg/L	AO	0.034	±0.180	0	0 - 1.6
Iron	252	0.3 mg/L	AO	0.148	±0.462	0.1	0 - 6.1
Magnesium	317	200 mg/L	AO	60.760	±43.523	48	8 - 281
Manganese	307	0.05 mg/L	AO	0.142	±0.369	0.07	0 - 5.83
pH	315	6.5-9.0 pH units	AO	8.288	±0.533	8.3	5.3 - 10.1
Sodium	317	300 mg/L	AO	16.530	±33.177	11	1 - 556
Sulphate	317	500 mg/L	AO	291.139	±232.942	227	0 - 1355
Total Alkalinity	317	500 mg/L	AO	162.902	±58.317	154	48 - 472
Total Dissolved Solids	317	1,500 mg/L	AO	661.839	±346.692	566	173 - 2090
Total Hardness	317	800 mg/L	AO	440.492	±248.690	373	103 - 1519

*Saskatchewan Watershed Authority recommends the objective of <5 mg/L for dissolved organic carbon.

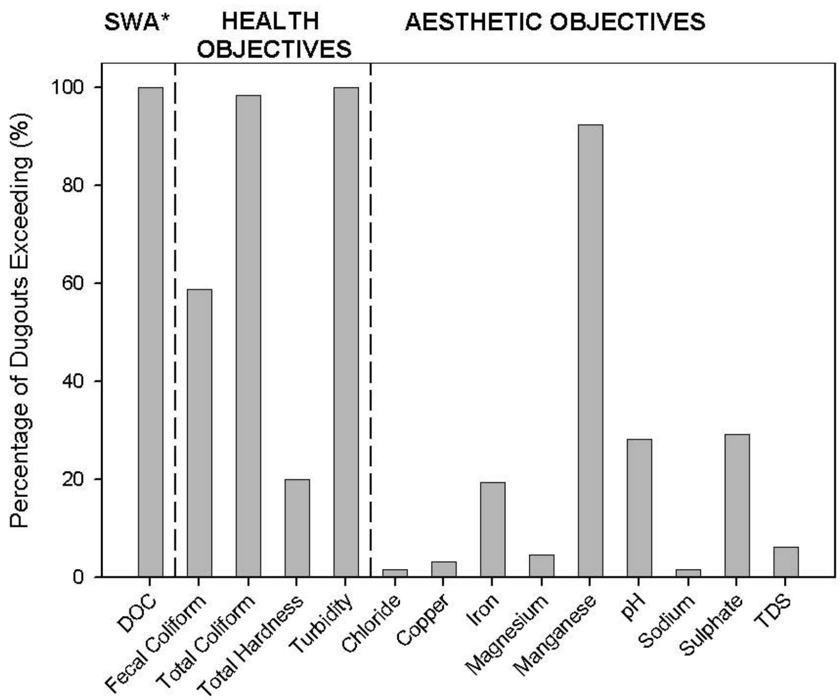

Figure 4 **Parameters and percentage of dugouts exceeding Saskatchewan's Drinking Water Standards and Objectives.**

Dissolved Organic Carbon

Dissolved organic carbon (DOC) is responsible for making lakes and dugouts look "tea" coloured. Precipitation, leaching and decomposition from surrounding terrestrial and wetland areas are the primary source of DOC additions to freshwater lakes and dugouts. Plants and algae within the water body also contribute to DOC concentrations. Although no provincial guideline for dissolved organics has been set, it is recommended by the Saskatchewan Watershed Authority that levels be below 5 mg/L to help minimize the problems associated with these compounds. Implications of DOC in drinking water are referenced in well water sampling section 3.1.

All of the dugouts sampled in the Spirit Creek Watershed exceeded the suggested guideline of <5 mg/L for DOC at least once (Figure 4). Values ranged from zero to 56 mg/L, with a mean of 18.054 (SD±7.696) mg/L and median of 17 mg/L (Table 3). Having land use information on the area surrounding each dugout would be useful in determining the cause of high DOC levels. Dissolved organic carbon levels could be influenced by any number of variables, including decomposing plant and animal material or soils.

Total and Fecal Coliform Bacteria

As described previously in the well water section 3.1, the presence of total coliform bacteria does not necessarily mean disease-causing organisms exist in the water; however, it can indicate the current or potential risk of pathogens which can include bacteria, protozoa and viruses. If the fecal coliform bacteria (sub-group of total coliform bacteria) are detected in drinking water, contamination by sewage or other sources of fecal matter including livestock is a possible cause. As total and fecal coliform bacteria are a health-related parameter, the *Maximum Acceptable Concentration* is zero organisms detectable per 100 mL of water (Saskatchewan Environment 2002).

Total and fecal coliform bacteria were exceeded in at least one sample for 98% and 59% of the 65 dugouts tested (Figure 4). Total coliform bacteria counts ranged from zero to 13,000 ct/100mL, with a mean of 250.567 (SD±999.224) ct/100 mL and median of 35 ct/100mL (Table 3). Fecal coliform bacteria counts ranged from zero to 2690 ct/100mL, with a mean of 16.563 (SD±162.437) ct/100mL and median of 0 ct/100mL. Counts for total and fecal coliform bacteria are variable and unpredictable in surface water. The results are strongly suggestive that surface water from the dugouts sampled is not an acceptable source of drinking water and would require treatment and monitoring prior to human consumption.

Turbidity

A description of turbidity parameters can be referred to in the well water sampling section 3.1. Sources of turbidity in surface waters are soil erosion, waste discharge, urban runoff and algal growth. The *Maximum Acceptable Concentration* for turbidity is 1 nephelometric turbidity unit (NTU) (Saskatchewan Environment 2002).

In the 65 dugouts sampled, 100% exceeded the MAC standard for turbidly in drinking water at least once (Figure 4). Though values ranged from zero to 68.7 NTU, the mean was 5.664 (SD±6.638) NTU and the median value was 3.66 NTU (Table 3). At values greater than 5 NTU, water turbidity becomes quite apparent to consumers, and the water may be rejected based purely on aesthetics. High turbidity in the dugouts sampled makes filtering and disinfection difficult for the purpose of human consumption. It is also important to note that, unlike groundwater, there is a higher probability that suspended solids are organically based and, therefore, that they will cause more of an obstacle to disinfection (Health Canada 1996).

Sodium and Chloride

Description for sodium and chloride can be referred to in well water sampling section 3.1. The *Aesthetic Objective* for sodium is 300 mg/L (Saskatchewan Environment 2002). Out of the 65 dugouts sampled, only 2% exceeded the objective for sodium. Values for sodium in sampled dugouts ranged from 1 mg/L to 556 mg/L, with a mean of 16.530 (SD±33.177) and a median of 11 mg/L.

Chloride is found naturally but in low concentrations in surface water. Typically in Canada most surface water sources do not exceed the objective for chloride unless they are influenced by the dissolution of salt deposits as a result of road salting or chemical industry effluent (Health Canada 1996). The *Aesthetic Objective* for drinking water is 250 mg/L (Saskatchewan Environment 2002). Out of the 65 dugouts sampled, only 2% exceeded the objective for chloride at least once (Figure 4). Values for chloride in sampled dugouts ranged from zero to 254 mg/L, with a mean of 5.423 (SD±15.647) and a median of 2 mg/L (Table 3).

Copper

Copper occurs naturally in surface water as a metal and in minerals. Found more frequently in surface water, copper is widely distributed in nature and is an essential element in human metabolism (Health Canada 1996). The *Aesthetic Objective* for copper in drinking water is 1 mg/L. Three percent of the 65 dugouts sampled exceeded this objective at least once (Figure 4). Values for copper ranged from zero to 1.6 mg/L, with a mean of 0.034 (SD±0.180) and a median of 0 mg/L (Table 3).

Iron

Iron has an *Aesthetic Objective* of 0.3 mg/L (Saskatchewan Environment 2002). Very little is known about iron levels in surface water. Concerns related to increased levels of iron in drinking water are explained in well water sampling section 3.1.

Of the 65 dugouts sampled, 19% of them exceeded the objective of 0.3 mg/L at least once (Figure 4). Values for iron in sampled dugouts ranged from zero to 6.1 mg/L, with a mean of 0.148 (SD±0.462) mg/L and a median of 0.1 mg/L (Table 3).

Magnesium

A description of magnesium in drinking water can be referenced in the well water sampling section 3.1. The *Aesthetic Objective* for magnesium is 200 mg/L (Saskatchewan Environment 2002).

Of the 65 dugouts sampled, 4% exceeded the objective of 200 mg/L at least once (Figure 4). Values for magnesium in the dugouts that were sampled ranged from 8 mg/L to 281 mg/L, with a mean of 60.760 (SD±43.523) and a median of 48 mg/L (Table 3).

Manganese

The presence of manganese in drinking water is described in the well water sampling section 3.1. The *Aesthetic Objective* for manganese is 0.05 mg/L.

Ninety-two percent of the 65 dugouts sampled exceeded the objective at least once (Figure 4), with manganese values ranging from zero to 5.83 mg/L, with a mean of 0.142 (SD±0.369) and a median of 0.07 mg/L (Table 3).

pH

The influence of pH on drinking water quality is described in the well water sampling section 3.1. Dugout pH is influenced by the addition of salts, acids, bases, and by photosynthesis. The *Aesthetic Objective* (Saskatchewan Environment 2002) sets a pH range of 6.5 to 9.0 as optimal for drinking water.

The pH exceeded the objective range of 6.5 to 9.0 in 28% of the 65 dugouts sampled at least once (Figure 4). Values for pH in dugouts ranged from 5.3 to 10.1, with a mean of 8.288 (SD±0.533) and a median of 8.3 (Table 3).

Sulphate

A description of sulphate in drinking water can be referenced in well water sampling section 3.1. The cycling of sulphur within a water body is complex and results in variable concentrations both spatially and seasonally. Sulphate occurs naturally in water and in concentrations greater than 500 mg/L, especially if magnesium levels are also high. High levels of sulphate and magnesium can have a laxative effect or cause gastrointestinal irritation. The *Aesthetic Objective* for sulphate is 500 mg/L.

Of the 65 dugouts sampled in the Spirit Creek Watershed, 28% exceeded the objective of 500 mg/L of sulphate at least once (Figure 4). Values ranged from zero to 1355 mg/L, with a mean of 291.139 (SD±232.942) and a median of 227 mg/L (Table 3).

Total Dissolved Solids

A description of total dissolved solids (TDS) in drinking water can be referred to in well water sampling section 3.1. The amount of minerals found in a water supply depends mainly on the types of rock or soil the water comes into contact with and the amount of water lost to evaporation relative to precipitation. A high mineral concentration can restrict the use of the water depending on the specific minerals present and their individual concentration. TDS can also be used as an indicator of the salinity of a water body. The *Aesthetic Objective* for TDS in drinking water is less than 1,500 mg/L (Saskatchewan Environment 2002).

Six percent of the 65 dugouts sampled in the Spirit Creek Watershed exceeded the drinking water objective of 1,500 mg/L at least once (Figure 4). Values ranged from 173 mg/L to 2090 mg/L, with a mean of 440.492 (SD±248.690) and a median of 566 mg/L (Table 3).

Total Hardness

In addition to the description of total hardness in well water sampling section 3.1, hard waters are usually found where water passes through calcareous deposit. In contrast, soft waters have low ion concentration, low salinity, and are usually derived from acidic igneous rock drainage. The *Aesthetic Objective* for total hardness is 800 mg/L (Saskatchewan Environment 2002).

Total hardness exceeded the 800 mg/L objective in 20% of the 65 dugouts sampled at least once (Figure 4). Values ranged from 103 mg/L to 1519 mg/L, with a mean of 440.492 (SD±248.690) and a median of 373 mg/L (Table 3).

3.3 Surface Water Runoff

In addition to well and dugout sampling, the *Spirit Creek Watershed Monitoring Committee* took samples of surface water runoff during the spring from 2001 and a storm event in June 2005. Sampling was conducted in four areas (sub-watersheds). Data was summarized parameter-by-parameter in two sets of graphs (Appendix D and E).

Box Plots

Box plots are arranged by sub-watershed area and primarily serve to demonstrate the year-to-year variability of parameter concentrations. It must be emphasized that the observed inter-annual variability is based on one surface water sample per year, which is insufficient to make any meaningful conclusions regarding the nature and magnitude of inter-annual variability, let alone potential impacts from specific land-use activities. These data are presented simply to show the results of this sampling program and emphasize the inherent variability of the data. It should also be noted that data from some of the downstream stations sites (e.g. sites SCWS#16 and SCWS#17) are included in more than one Area, and are repeated in the figures (see Appendix D).

The observed nutrient concentrations were high, which is typical of many prairie streams. Total phosphorus concentrations were usually greater than the objective of 0.1 mg/L that the *Saskatchewan Watershed Authority* uses in its assessment of surface water. Much of the total phosphorus fraction was in the form of soluble reactive phosphorus (or ortho-phosphorus), suggesting that it is readily available for uptake by bacteria and algae. Likewise, concentrations of total nitrogen (in this case, total Kjeldahl nitrogen + nitrate) were high. Total ammonia nitrogen was also abundant, especially during spring runoff in 2004 and 2005. The high concentrations of dissolved nutrients (soluble reactive phosphorus, total ammonia nitrogen and nitrate) suggest that microorganisms were not nutrient limited during the periods of sampling; however, these nutrients contribute to the overall nutrient loading of downstream lakes.

Some of the key nutrients (e.g. total phosphorus, total Kjeldahl nitrogen and total ammonia nitrogen), biological oxygen demand (BOD), and microbiological indicators (e.g. total coliforms, fecal streptococcus) appeared to increase in concentration from 2001-2002 to 2004-2005. It is important to again emphasize that only one sample was taken during spring runoff each year, and there was no corresponding measure of flow (therefore no estimates of load could be made). It is currently unknown what effects sample timing or flow volume among years had on the observed concentrations.

In contrast to nutrients, BOD and microbiological indicators, measures of ionic strength and some of the individual ions appeared to decrease over the same time period (conductivity, total dissolved solids, calcium, and sulphate). It should be noted that these trends were not followed by all parameters (e.g. nitrate, fecal coliform bacteria, and chloride).

Sampling during the rain event in June 2005 demonstrates that the above-noted general trends may be an artifact of sample timing or may be due to the amount of water in spring runoff for any given year rather than reflecting long-term trends. For example, despite the noticeable decrease in the range of conductivity and total dissolved solids values from 2001-2002 to 2004-2005, the sample taken during the June rain event in 2005 had the greatest median value for conductivity and total dissolved solids of the samples measured. Similarly, some of the parameters that appear to have increased in the spring runoff samples during the 2004-2005 period were found to be at relatively low concentrations during the 2005 rain sampling event (e.g. total phosphorus, total ammonia nitrogen, BOD, fecal streptococcus). The variability observed within the 2005 calendar year only serves to demonstrate the critical importance of having a sufficient number of samples and an appropriate sampling design to address the original question regarding the influence of intensive livestock operations on water quality.

Line Graphs

Like the box plots, the line plots are separated by Area. Within each Area, the specific sampling location was determined using the legal description and identifying adjacent streams. The stream distance between stations was then calculated using topographic maps. Two headwater streams were identified in each of Areas 1 and 2. These streams joined at a point further downstream (Figure 5). In the line graphs, these different headwater streams are differentiated with unique points (open vs. filled). The last two sampling stations (SCWS#16 and SCWS#17) are common to all streams. In Area 3, several points were found to lie on or adjacent to a stream; these points are connected (filled points with solid line). It was not clear whether the other two sampling stations in Area 3 flowed downstream and are, therefore, represented by unconnected points. Area 4 had one stream, and data was only collected during 2004 and 2005. Some sites were not sampled in 2001, so information from 2001 is not included in these graphs.

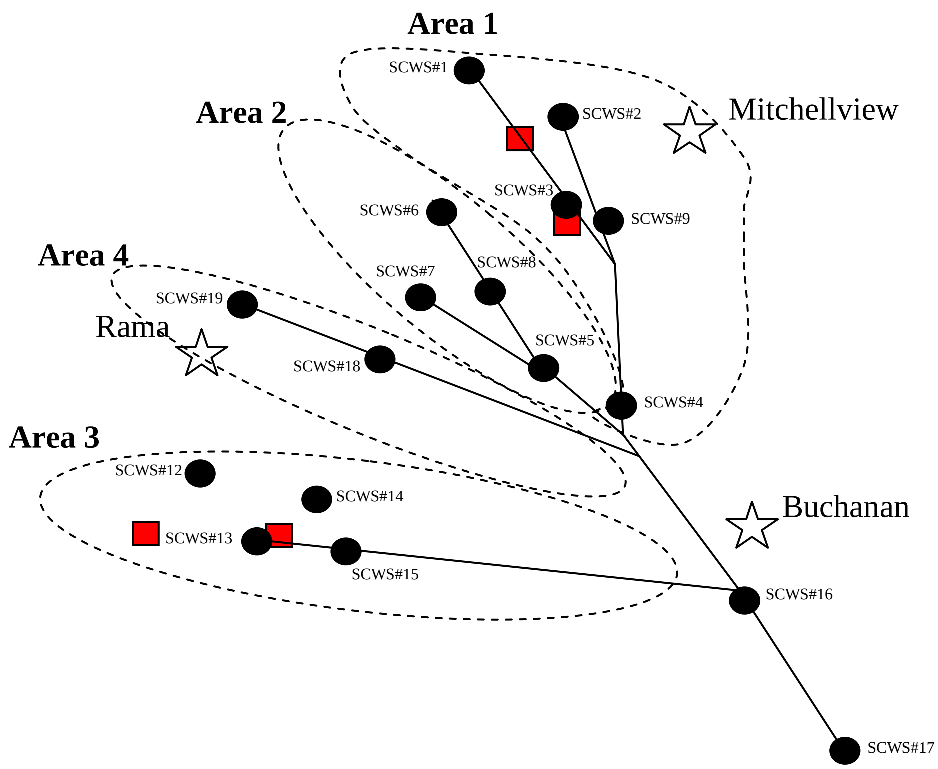

Figure 5 Diagrammatic figure showing the assumed stream relationships between sampling points (black circles). The dashed lines enclosing the sampling points represents sampling sites in the four respective Areas. The relative location of hog barns (red squares) and municipalities (open stars) are given for points of reference. Sites SCWS#16 and SCWS#17 are downstream from all four Areas.

SCWS#16 and SCWS#17 are downstream of standing water (e.g. SCWS#17 is downstream of Patterson Lake). This is critical to consider when evaluating spatial trends because water slows down in these areas, providing the opportunity for increased particle settling. Substantive plankton populations can establish in slower moving or standing water, thereby increasing the potential uptake of dissolved nutrients and building biomass (e.g. increasing chlorophyll concentrations). The settling of particle and plankton growth dynamics depends, in part, on the actual flows in each year and other factors such as macrophyte abundance, water temperature, and light availability.

As noted above, Areas 1, 2, and 3 had sampling stations on two different upstream streams. Typically, parameter concentrations at these adjacent sites were similar on a given sampling date, especially for pH, total phosphorus and conductivity (total dissolved solids and constituent ions), bacteria and chlorophyll. However, at times streams in adjacent Areas demonstrated different patterns (Appendix E). This suggests that there is a regional similarity at a small scale where differences observed from year to year are driven by external factors (weather) rather than localized differences such as soils and topography. At the larger regional scale, a difference in soil geology, topography, etc. among sub-watersheds increases in importance for determining constituent concentrations. However, variability among sites is small relative to inter-annual variability, suggesting the importance of climatic conditions for explaining most of the observed variability among all the Areas.

As noted in the box plots, there is inter-annual variation of parameter concentrations. For some parameters, in some years, there appears to be an increase in concentration from upstream to downstream locations, whereas in other years the opposite trend is observed or there is no clear trend.

Total phosphorus concentration increased from the upstream to downstream sampling stations in some years and decreased or remained relatively stable in other years (Appendix E). A stabilization or slight decrease in total phosphorus was often noted at the furthest downstream station (SCWS#17). Conductivity and total dissolved solids tended to increase at the downstream stations. This may be a consequence of both the distance traveled and the change in soil type at the downstream stations.

In 2004 at two sampling stations in Area 2, concentrations of aluminium and iron were observed to be high compared to downstream stations and stations in other Areas (Appendix E, Figure E14 and E15). These high metal concentrations were observed at Stations SCWS#7 and SCWS#5. On the graph, these are the two filled (black) points and correspond to distances of approximately 29 and 23 kilometers from SCWS#17 at the south end of Patterson Lake (see Figure 3). Turbidity was also noted to be high relative to other stations. Higher concentrations of aluminium, iron and turbidity were also found in 2001 (see box plot in Appendix). At this time no explanation for these observations can be provided because the circumstances around the time of sampling are unknown.

Fecal coliform bacteria tended to be in greater concentration at upstream sites in Areas 1 and 2, although this was not the case in 2005 when high concentrations of fecal coliform bacteria were observed at the second furthest downstream station, SCWS#16 (Appendix E). In contrast, the two upstream sites in Area 3 tended to have low fecal coliform bacteria counts. Total coliform and fecal streptococcus bacteria generally reached their highest concentrations at the upstream stations and stabilized along the stream course prior to deceasing at the downstream stations (SCWS#16 and/or SCWS#17).

As expected, chlorophyll concentrations tended to be low in the upstream samples. When chlorophyll did increase, it was typically at one or both of the downstream stations (SCWS#16 and/or SCWS#17). Turbidity was generally found to decrease at the furthest downstream station (SCWS#17).

Livestock Operations

To provide a cursory comparison of potential impacts from intensive livestock on water quality, average water quality values downstream of livestock operations in Area 1 and 3 were matched against sampling sites in Areas 2 and 4. The sites included in this comparison were: Area 1 - SCWS#2, 3, 9 and 4; Area 2 - SCWS#6, 7, 8 and 5; Area 3 - SCWS#12, 13, 14, and 15; and Area 4 - SCWS#18 and 19.

In 2004 and 2005 the average total ammonia nitrogen and total phosphorus were greater in Areas 1 and 3 (Areas with intensive livestock operations) compared with Areas 2 and 4 (Figure 6). However, there was high variability in all areas, and the previous years did not show the same trend of having higher nutrients in Areas 1 and 3. The data analyzed in Figure 6 represents, at best, a cursory examination of nutrient concentrations and does not consider where manure from the intensive livestock operations was spread (e.g. manure was spread in Area 2). Due to the lack of a rigorous sampling design aimed at addressing impacts of livestock operations, no further analysis was conducted and no conclusion can be made about potential impacts from this land-use activity.

There were no clear, consistent differences among Areas for conductivity, biological oxygen demand or turbidity. Nutrients and biological oxygen demand tended to be greater in 2004 and 2005, whereas conductivity and corresponding measures of ionic composition were lower. This may be due to differences in runoff volume; however, no known measures of spring runoff or winter precipitation are available.

Bacterial measures were quite variable, but showed no clear, consistent difference among the sites (Figure 7). Total coliform bacteria abundance was greater in 2004 and 2005 (note the log scale). This follows the same trend as some of the nutrients, and is suggestive of differences in meteorological conditions among the years.

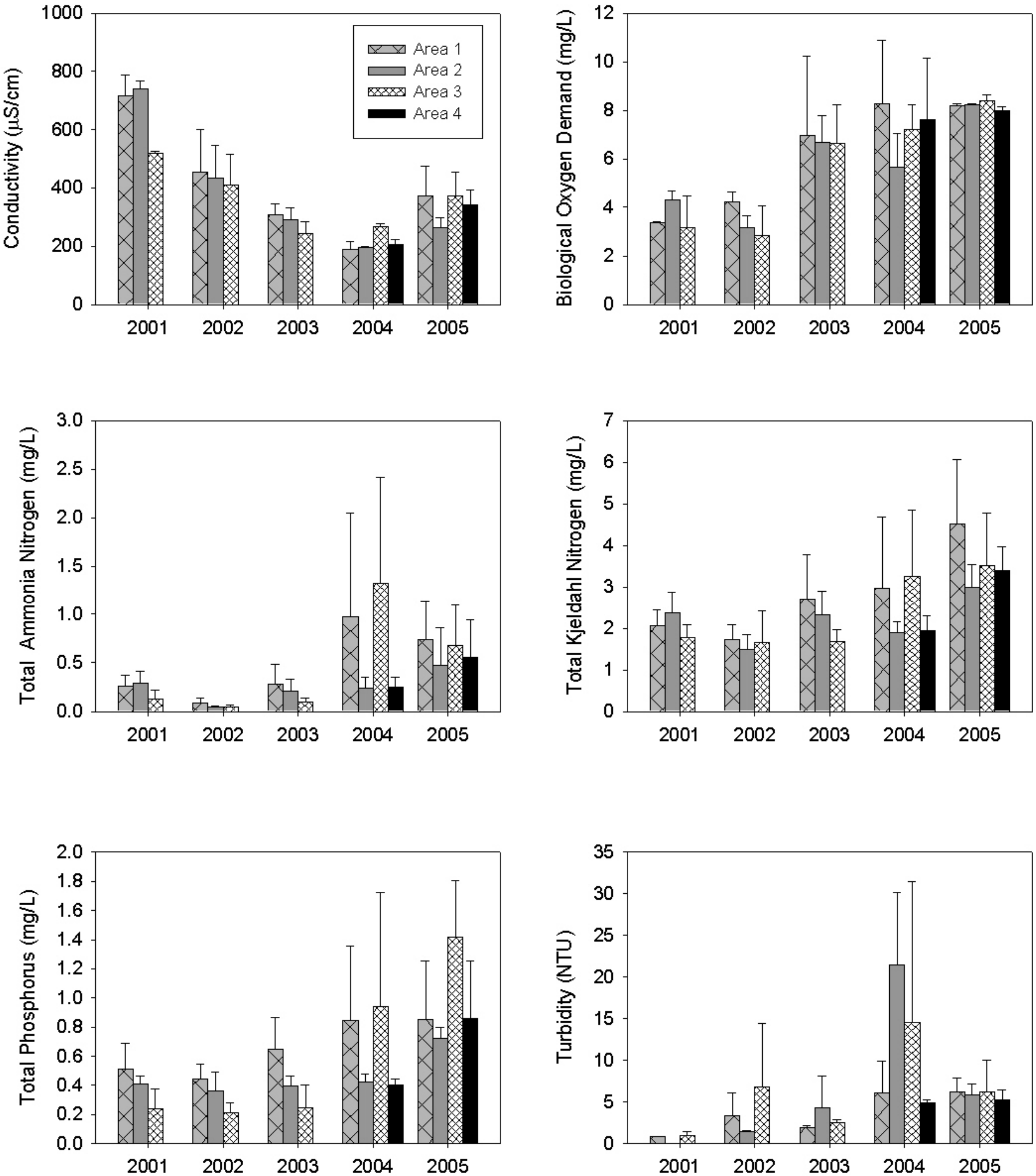

Figure 6 Comparison of average parameter values of sites downstream of intensive livestock operations for Areas 1 and 3 and those in Areas 2 and 4. The sites downstream of all Areas (SCWS#16 and 17) are not included in these averages. Error bars represent one standard deviation.

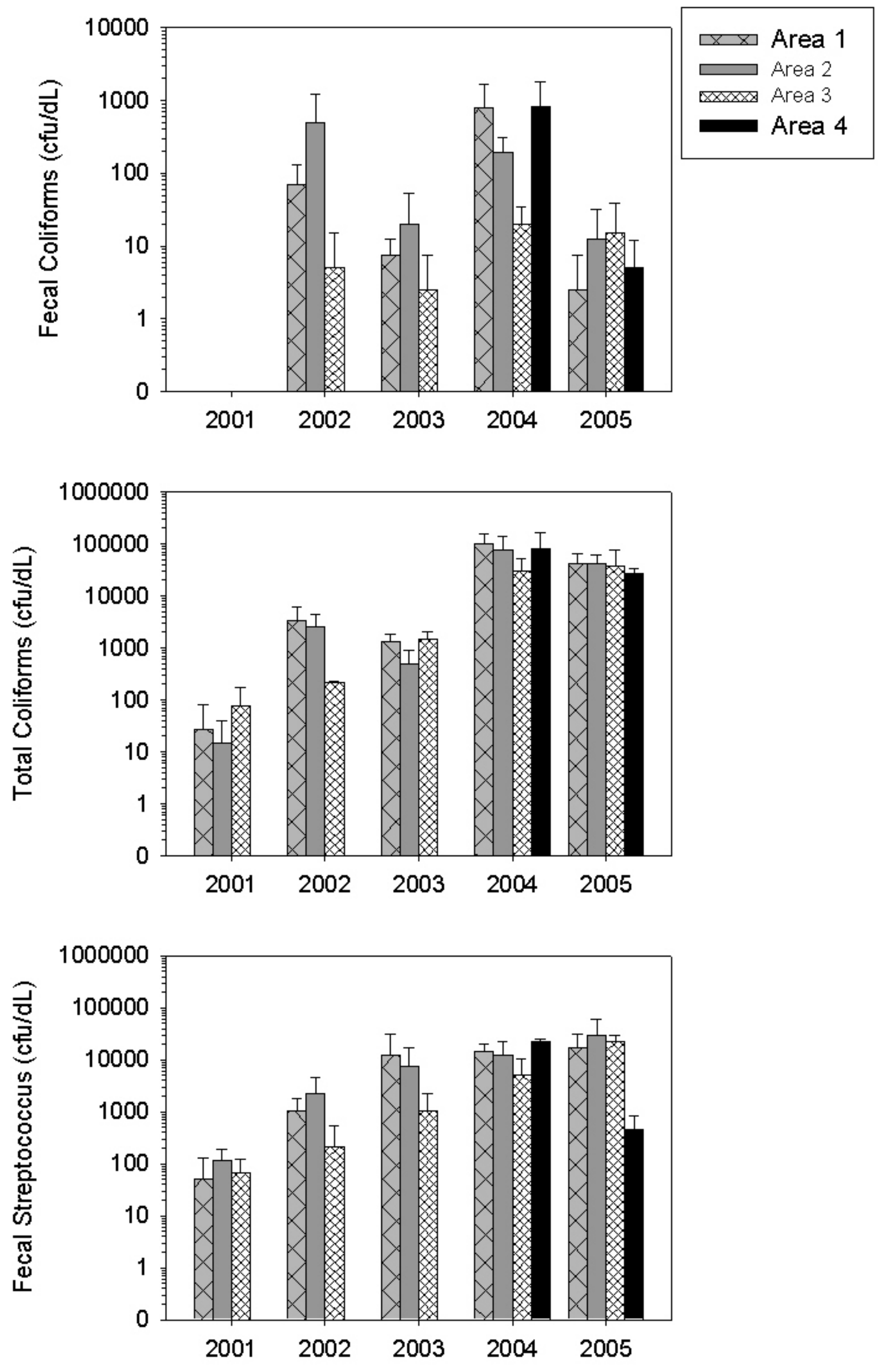

Figure 7 Comparison of average coliform values for sites downstream of intensive livestock operations for Areas 1 and 3 and those in Areas 2 and 4. The sites downstream of all Areas (SCWS#16 and 17) are not included in these averages. Error bars represent one standard deviation. Note the log scale.

3.4 Good Spirit Lake Water Quality

Good Spirit Lake is the receiving water body for the Spirit Creek Watershed. Monitoring the lake is important in order to determine changes in the lake water quality over time. Saskatchewan Watershed Authority gives annual updates on the current status of Good Spirit Lake's water quality using the *Water Quality Index* (Canadian Council of Ministers of the Environment 2002).

As shown in Figure 8, Good Spirit Lake regularly scores *Good* to *Excellent* in the *Water Quality Index*. Good Spirit Lake had excellent water quality in 1998; however, in addition to having high water levels in that period, the lake was only sampled three times. Though water was released in the fall of 1999 until February 2000 and lake levels were high, there were exceedances in both pH (9.1) and phosphorus (0.11 mg/L) in 1999, taking the WQI score down to 86 (*Good*).

The lake received a WQI score of 94 (*Good*) in 2000, due to one exceedance in phosphorus (0.14 mg/L); however, with increased spring runoff and no exceedances in 2001, the lake again received a score of 100 (*Excellent*). Coinciding with the start of a localized drought in the Spirit Creek region, parameters contributing to the low score in 2002 were phosphorus (0.17 mg/L and 0.13 mg/L), fecal coliform bacteria (410 ct/100mL) and chlorophyll *a* (71.97 µg/L). Excursions in dissolved oxygen (3.13 mg/L) and pH (9.1) in 2003 resulted in a score of 89 (*Good*). Lake water levels in 2004 were slightly higher than the previous two years, and with only two exceedances in phosphorus (0.14 mg/L & 0.17 mg/L) the lake's WQI score rose to 95 (*Excellent*). The lower score of 88 (*Good*) in 2005 can be attributed to the exceedance of three parameters: phosphorus (0.12 mg/L to 0.14 mg/L), chlorophyll *a* (52.33 µg/L) and pH (9.02).

As described in the well water sampling section 3.1, fecal coliform bacteria are present in the lower intestine of warm blooded animals and therefore indicate contamination from livestock, wildlife or human waste. For the purpose of recreation, the *Saskatchewan Surface Water Quality Objectives* (Saskatchewan Environment 2006) state that fecal coliforms should not exceed 200 organisms per 100 mL of water. Though the fecal coliform bacteria count in 2000 was higher than the objective, it decreased to within acceptable counts in subsequent samples, suggesting it was only an isolated incident. Good Spirit Lake is still considered to have good bacteriological water quality for contact recreation.

Total phosphorus is a measure of all phosphorus forms including dissolved and particulate organic phosphates from algae and other organisms, inorganic particulate phosphorus from soil particles and other solids, and polyphosphates from detergents and dissolved orthophosphates. The measure for total phosphorus is used in the *Water Quality Index* and has exceeded the objective for surface water quality in Good Spirit Lake; however, not all of the total phosphorus is available for use by aquatic plants and algae.

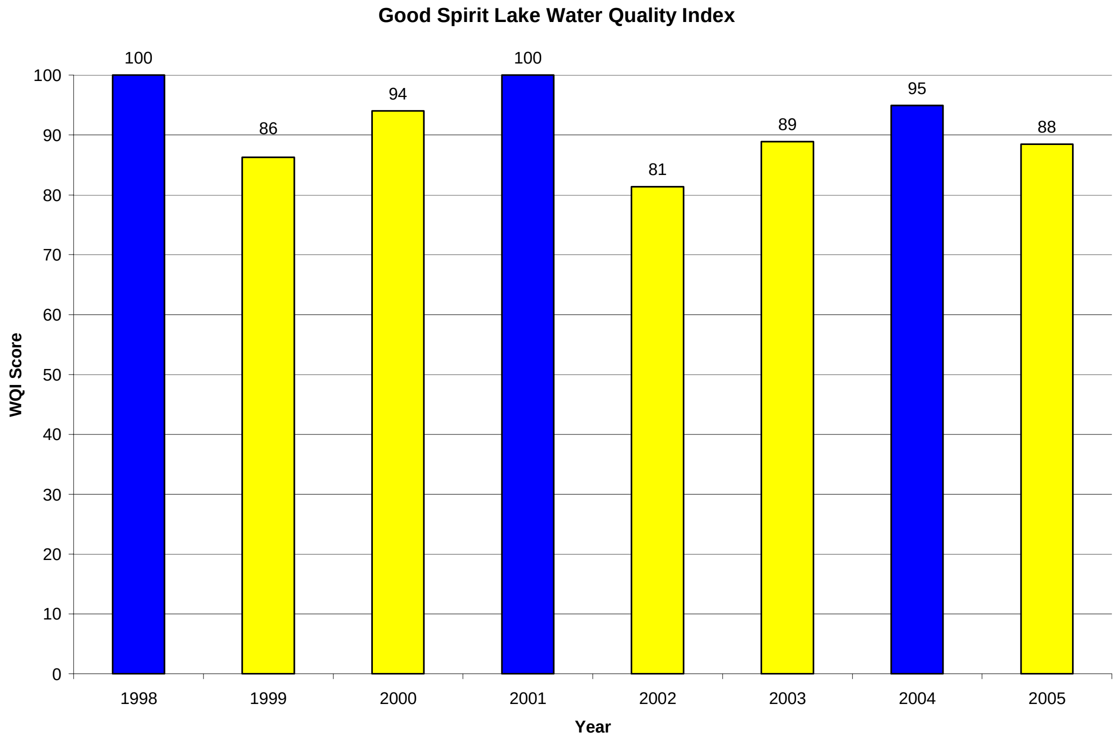

Figure 8 Water Quality Index score for Good Spirit Lake, 1998 to 2005. Blue bars indicate Excellent water quality, while yellow bars represent Good water quality.

A description of pH can be referenced in the well water sampling section 3.1. The pH affects most chemical and biological reactions within the lake. Largely determined by geology, pH can be influenced by other factors including pollution. The pH in Good Spirit Lake indicates that it is a slightly alkaline system and therefore we can expect to continue to have excursions with this parameter.

Chlorophyll *a* (a pigment found in plants and algae) is used to measure the productivity of the lake. An exceedance in chlorophyll *a* may indicate a year or season where algae were particularly more abundant due to increased available nutrients and optimal conditions for growth. Though it can show increases in lake productivity over time, there have only been two exceedances noted since 1998.

Dissolved oxygen (amount of oxygen dissolved in the water for aquatic life respiration) had only one excursion in the winter of 2003. Though the level was considered lower than what is required for fish, it is important to note that dissolved oxygen is not uniform throughout the lake and fish as well as other biological organisms do find more optimal areas in which to inhabit.

4.0 CONCLUSIONS

4.1 Well Water Sampling

Water quality was variable between and within individual wells sampled. Analysis with descriptive statistics and box plot representation showed extreme variability for most parameters, most likely due to multiple factors such as inherent variability associated with precipitation and season, localized land-use, and geology. Differences in individual wells from year to year as well as between spring and fall were not observed due to natural variability.

Wells sampled in the Spirit Creek Watershed exceeded health parameters twice as often as the provincial data set, as indicated by the *Rural Water Quality Advisory Program*. Though health standards were frequently exceeded for total coliform bacteria, fecal coliform bacteria and nitrates, there were no exceedances in the 25 wells for arsenic and selenium. Without site-specific information on land-use and well characteristics it is impossible to determine the cause of high bacteria and nitrates. Provincial testing for uranium indicates that 16% of wells tested exceed the health standard of 20 µg/L, however, none of the wells in the Spirit Creek Water Quality Assessment were tested for uranium.

Aesthetic Objectives exceeded in the Spirit Creek Watershed were 25% lower then the findings through the *Rural Water Quality Advisory* Program. Though *Aesthetic Objectives* were frequently exceeded for iron, manganese, total dissolved solids, magnesium, and sulphate, there were no exceedances in the 25 wells sampled for sodium and chloride. Despite the benefit of knowing site-specific information on land-use and well characteristics for some parameters, it is also important to take into account the local geology.

Overall, well water quality in this area was typical from a health and aesthetic perspective. Bacteria and nitrate were frequently present above the *Maximum Acceptable Concentrations*. As with most shallow wells in Saskatchewan, wells in the Spirit Creek Watershed are not recommended for consumption prior to treatment.

4.2 Dugout Water Sampling

Because surface water bodies are naturally susceptible to environmental influences such as climate and land-use, dugout water quality varied greatly between sites. For individual dugouts, year to year and spring to fall differences were not apparent due to natural variability of the parameters measured. Analysis with descriptive statistics and box plot representation showed extreme variability for most parameters, most likely due to multiple factors such as: inherent variability associated with precipitation and season, localized land-use, and geology.

Dugouts sampled in the Spirit Creek Watershed that exceeded *Municipal Drinking Water Standards and Objectives* could not be compared to provincial data at this time. This report represents more of a qualitative description of the drinking water quality of surface dugout water in the Spirit Creek Watershed. Future comparison of dugout water quality in the Spirit Creek Watershed to water quality in dugouts province-wide would put the number of exceedances into perspective.

Health standards frequently exceeding the *Maximum Acceptable Concentration* in dugouts included: total coliform bacteria, fecal coliform bacteria and turbidity. All surface waters that are open to the environment are susceptible to bacteria including coliform bacteria. Due to the nature of turbidity (including both inorganic and organic particulate matter), is not unusual that this parameter was exceeded at least once in all 65 dugouts tested.

Aesthetic Objectives frequently exceeded in dugouts included: sodium, chloride, copper, iron, magnesium, manganese, pH, sulphate, total dissolved solids and total hardness. At least one *Aesthetic Objective* was exceeded in 98.5% of the dugouts sampled, which strongly suggests that surface water from dugouts are not an acceptable source of drinking water and would require treatment and monitoring prior to human consumption.

Due to exceedances of *Municipal Drinking Water Standards* (i.e. for bacteria and turbidity) as well as *Aesthetic Objectives* (i.e. sodium, chloride, copper, iron, magnesium, manganese, pH, sulphate and total dissolved solids), dugout water quality measurements suggest that dugouts require treatment prior to being used as a domestic or drinking water source.

4.3 Surface Water Runoff

The water quality parameters measured were observed to have typical concentrations for prairie streams. There was substantial inter-annual variability, presumably driven by climate, but perhaps also due to sample design. Many of the parameters were observed to reach high concentrations at the upstream sampling location. It was noted that, although the variance was high, average ammonia and total phosphorus in the Areas with the intensive livestock operations were greater in 2004 and 2005 than in Areas 2 and 4. The lack of a rigorous sampling design prohibits the ability to draw conclusions about whether this observation is significant, due to intrinsic properties of the respective Areas or a result of land-use activities. In Area 2 during 2001 and 2004 there was an observation of high concentrations of aluminium and iron, along with high turbidity at two adjacent stations along one of the streams.

There was large inter-annual variability of parameter concentrations, which makes it impossible to assess possible impacts/contributions from agricultural operations. There was a single water quality sample taken during spring and no corresponding measures of flow (therefore load cannot be estimated). The data summarized is useful for understanding the general background information about these sites; however, without more frequent measurements and an understanding of the contribution from other sources it is impossible to estimate the contribution from intensive livestock operations. This includes determining if the higher nutrients observed in Areas 1 and 3 in 2004 and 2005 are significantly greater than those measured in the other two Areas.

4.4 Good Spirit Lake Water Quality

Good Spirit Lake consistently scores *Good* to *Excellent* according to the *Water Quality Index* (Canadian Council of Ministers of the Environment 2002). Phosphorus and pH frequently fall outside the *Interim Surface Water Quality Objectives* (Saskatchewan Environment 2006), while chlorophyll *a*, fecal coliform bacteria and dissolved oxygen have rare excursions or exceedances.

Overall, the *Water Quality Index* for Good Spirit Lake indicates little change over the past eight years. Parameters which regularly deviate from the *Interim Surface Water Quality Objectives* (Saskatchewan Environment 2006) are likely influenced by local geology, climate and natural cycles within the lake. Excursions or exceedances in other parameters do not indicate poor lake water quality as they were not recurrent.

5.0 RECOMMENDATIONS

- Undertake a risk assessment of aquifer vulnerability. Aquifer characteristics including depth, overlying burden (permeability), direction of groundwater flow, and density of wells should be considered when determining the risk to the aquifer. Aquifer sensitivity mapping will help in the design of groundwater monitoring and ground water management activities.
- With naturally high (exceeding the *Saskatchewan Municipal Drinking Water Quality Standards*) levels of uranium occurring elsewhere in the province, it is advisable that the drinking water sources in the Spirit Creek Watershed be analyzed for this parameter.
- Re-evaluate the surface water runoff sampling sites and monitoring protocols, including those intended to represent control sites. Appropriate sampling methodology (i.e. flow weighted sampling) would be beneficial when trying to determine total loading. An assessment of land-use activities surrounding sample sites would be beneficial to determine if the sites are providing representative and meaningful data.
- If further data is required on the impact of specific activities in these sub-watersheds, a more intensive sampling regime or a different approach should be explored.
- For future reference with regard to well and dugout sampling, it is imperative that site-specific land-use practices (i.e. location of sewage lagoons/tanks, proximity to livestock, manure spreading, spraying, etc.) and well characteristics (i.e. age, depth, GPS location, cribbing material, etc.) be determined. In addition to this information, consistent paired sampling of all wells chosen for the study would be beneficial when assessing trends.

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Appendix A

Descriptive Statistics for Water Quality Parameters Tested in Groundwater and Surface Water

Table A1 – *Municipal Water Quality Standards and Objectives* as well as descriptive statistics for groundwater (wells) of water quality parameters tested for in the assessment of the Spirit Creek Watershed from 2000 – 2004.

Parameter	Stand./ Object.	Sample Number	Mean	Stand. Dev.	Median	Range (min. to max.)
Aluminium (mg/L)	-	89	0.018	0.038	0	0 - 0.22
Ammonia as N (mg/L)	-	115	0.096	0.379	0.03	0 - 4
Arsenic (µg/L)	25	85	$4.4x10\text{-}^{4}$	0.001	0	0 - 0.009
Barium (mg/L)	1	111	0.095	0.099	0.08	0.009 - 1
Bicarbonate (mg/L)	-	116	414	138	386	181 - 932
Biological Oxygen Demand (mg/L)	-	116	0.3	0.4	0.2	0 - 2.6
Boron (mg/L)	5	81	0	0	0	0 - 0
Calcium (mg/L)	-	116	113	47	103	38 - 226
Chloride (mg/L)	250	116	12	30	3.5	0 - 196
Conductivity (µS/cm)	-	116	1066	477	1006	381 - 3020
Copper (mg/L)	1	87	0.013	0.040	0	0 - 0.2
Dissolved Organic Carbon (mg/L)	<5	116	7.2	4.5	6	0 - 24
Fecal *Streptococcus* (ct/100mL)	-	111	23	136	0	0 - 1400
Fecal Coliform (ct/100mL)	0	108	10	65	0	0 - 520
Heterotrophic Plate Count (ct/mL)	500	88	7300	44900	153	0 - 300000
Iron (mg/L)	0.3	95	1.1	4.3	0	0 - 34.7
Lead (mg/L)	0.01	84	$3.0x10\text{-}^{3}$	0.001	0	0 - 0.006
Magnesium (mg/L)	200	116	78	51	67	19 - 351
Manganese (mg/L)	0.05	101	0.32	1.03	0.03	0 - 8
Nitrate (mg/L)	45	108	32	59	15	0 - 428
Orthophosphate (mg/L)	-	115	0.10	0.06	0.1	0 - 0.57
pH	6.5	116	7.5	0.3	7.5	6.7 – 10.0
Potassium (mg/L)	-	115	8	6	6	2 - 31
Selenium (mg/L)	0.01	90	0.001	0.001	0	0 - 0.005
Sodium (mg/L)	300	116	18	21	15	2 - 134
Sulphate (mg/L)	500	116	243	238	186	0 - 1563
Total Alkalinity (mg/L)	500	116	340	113	316	148 - 764
Total Dissolved Solids (mg/L)	1500	116	917	435	866	326 - 2893
Total Hardness (mg/L)	800L	116	602	293	581	194 - 1915
Total Kjeldahl Nitrogen (mg/L)	-	115	0.797	0.497	0.7	0 - 2.5
Total Phosphorous (mg/L)	-	116	0.13	0.08	0.11	0.04 - 0.59
Total Coliform (ct/100mL)	0	109	36	111	0	0 - 610
Turbidity (NTU)	<1.0	114	10	45	0.54	0 - 412
Zinc (mg/L)	5	83	0.18	0.70	0	0 - 4

- means no standards or objectives for that parameter

Table A2 – *Municipal Drinking Water Quality Standards and Objectives* as well as descriptive statistics for surface water (dugouts) of water quality parameters tested for in the assessment of the Spirit Creek Watershed from 2000 – 2004.

Parameter	Stand./ Object.	Sample Number	Mean	Stand Dev.	Median	Range (min to max)
Aluminum (mg/L)	-	256	0.039	0.074	0.02	0 - 0.9
Ammonia as N (mg/L)	-	317	0.124	0.340	0.04	0 - 4.05
Bicarbonate (mg/L)	-	317	185	77	181	12 - 576
Biological Oxygen Demand (mg/L)	-	317	4	4	3	0 - 41
Calcium (mg/L)	-	317	76	34	69	20 - 188
Chloride (mg/L)	250	317	5	16	2	0 - 254
Chlorophyll A (µg/L)	-	307	44	81	18	0 - 764.44
Conductivity (µS/cm)	-	317	870	694	735	235 - 10820
Copper (mg/L)	1	224	0.034	0.180	0	0 - 1.6
Dissolved Organic Carbon (mg/L)	5	317	18	8	17	0 - 56
Fecal *Streptococcus* (ct/100mL)	-	277	28	106	2	0 - 1260
Fecal Coliform (ct/100mL)	0	284	17	162	0	0 - 2690
Heterotrophic Plate Count (ct/mL)	500	257	13389	50401	1400	0 - 300000
Iron (mg/L)	0.3	252	0.148	0.462	0.1	0 - 6.1
Magnesium (mg/L)	200	317	61	44	48	8 - 281
Manganese (mg/L)	0.05	307	0.142	0.369	0.07	0 - 5.83
Nitrate (mg/L)	45	291	0.777	2.893	0	0 - 36
Nitrate-Nitrite (mg/L)	-	39	0.115	0.343	0	0 - 1.5
Orthophosphate (mg/L)	-	317	0.178	1.328	0.04	0 - 23.23
pH	9	315	8.3	0.5	8.3	5.3 - 10.1
Potassium (mg/L)	-	307	21	12	18	5 - 66
Selenium (mg/L)	0.01	223	$3.6x10-^{5}$	0.000	0	0 - 0.002
Sodium (mg/L)	300	317	17	33	11	1 - 556
Sulphate (mg/L)	500	317	291	233	227	0 - 1355
Total Alkalinity (mg/L)	500	317	163	58	154	48 - 472
Total Dissolved Solids (NTU)	1500	317	662	347	566	173 - 2090
Total Hardness (mg/L)	800	317	440	249	373	103 - 1519
Total Kjeldahl Nitrogen (mg/L)	-	316	2.2	1.7	1.9	0.03 - 20
Total Phosphorus (mg/L)	-	317	0.24	0.37	0.13	0 - 3.45
Total Coliform (ct/100mL)	0	282	251	999	35	0 - 13000
Turbidity (NTU)	1	317	5.7	6.6	3.7	0 - 68.7

- means no standards or objectives for that parameter

Appendix B

Box Plots for Parameters with at Least One Sample Exceeding a Municipal Water Quality Standard or Objective

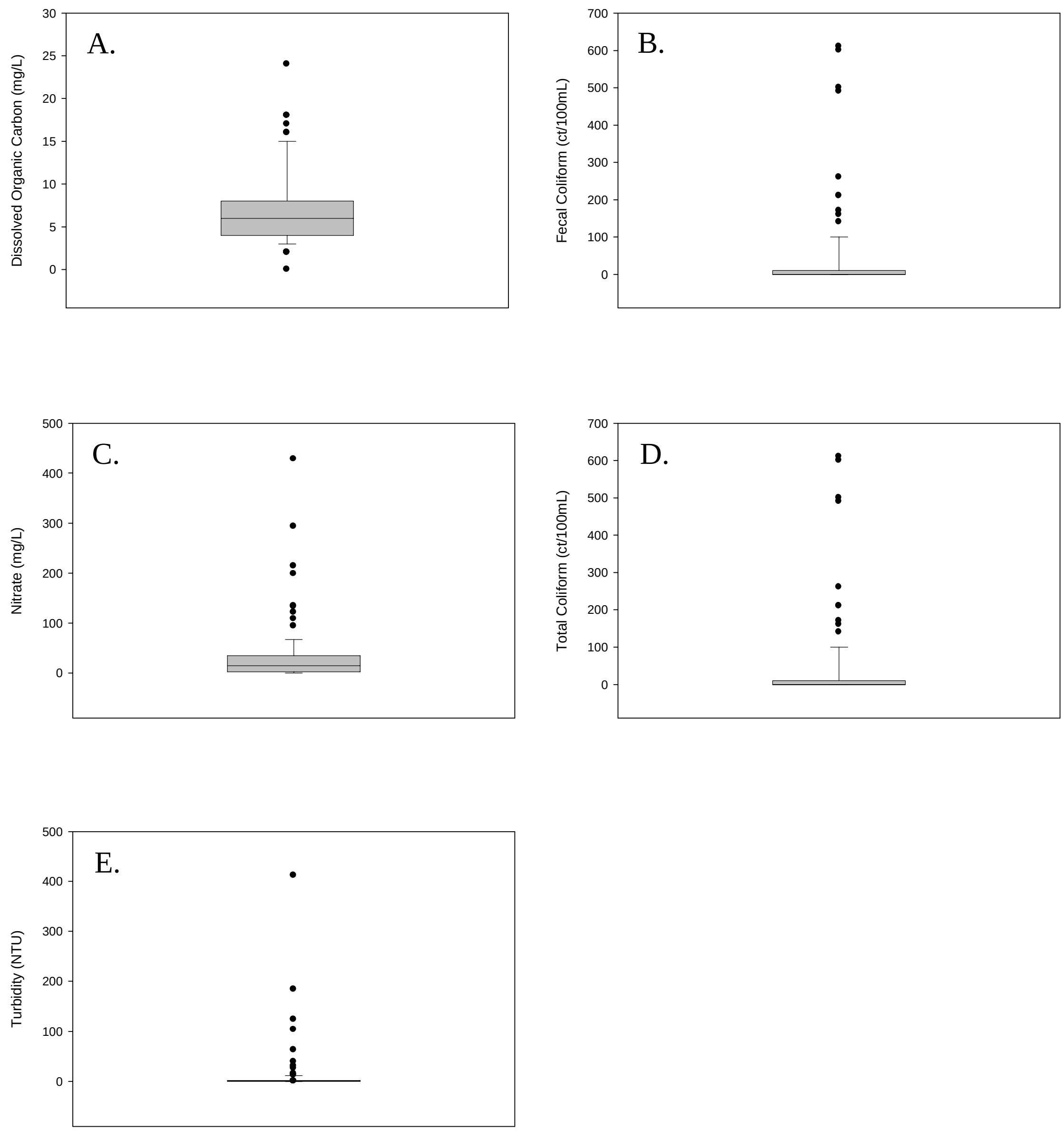

Figure B1 - Box plots demonstrating the variability of parameters tested in groundwater (25 wells) with at least one sample exceeding the level suggested by the Saskatchewan Watershed Authority (A - Dissolved Organic Carbon) or; exceeding a *Municipal Drinking Water Standard* (B - Fecal Coliform Bacterial Count, C - Nitrate, D – Total Coliform Bacterial Count, E - Turbidity).

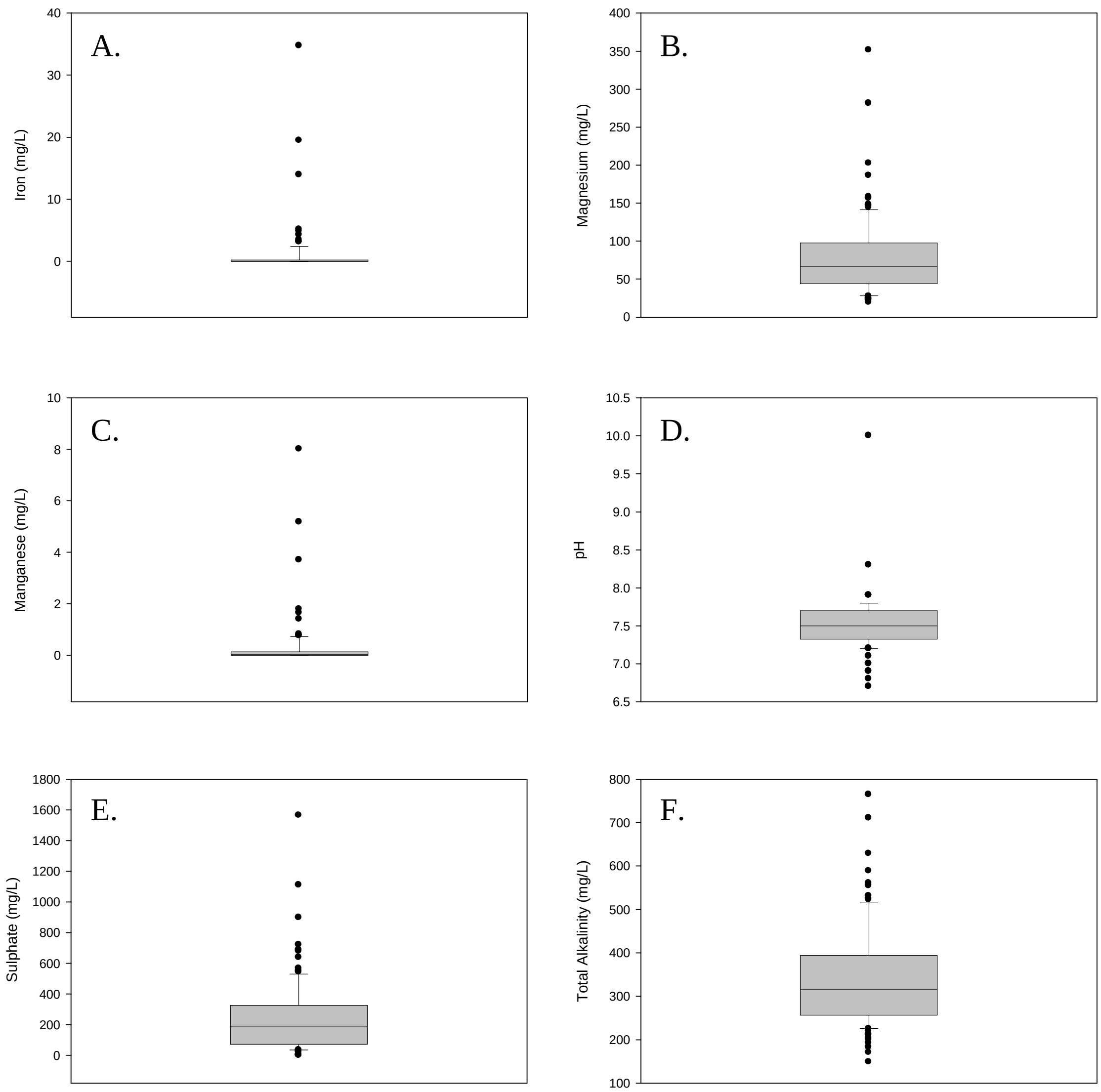

Figure B2.1 - Box plots demonstrating the variability of parameters tested in groundwater (25 wells) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* (A - Iron, B - Magnesium, C - Manganese, D - pH, E - Sulphate, F - Total Alkalinity).

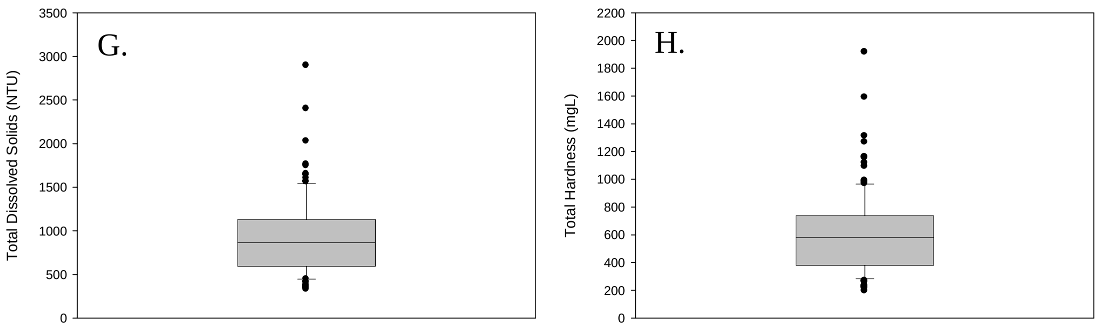

Figure B2.2 - Box plots demonstrating the variability of parameters tested in groundwater (25 wells) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* (G - Total Dissolved Solids, H - Total Hardness).

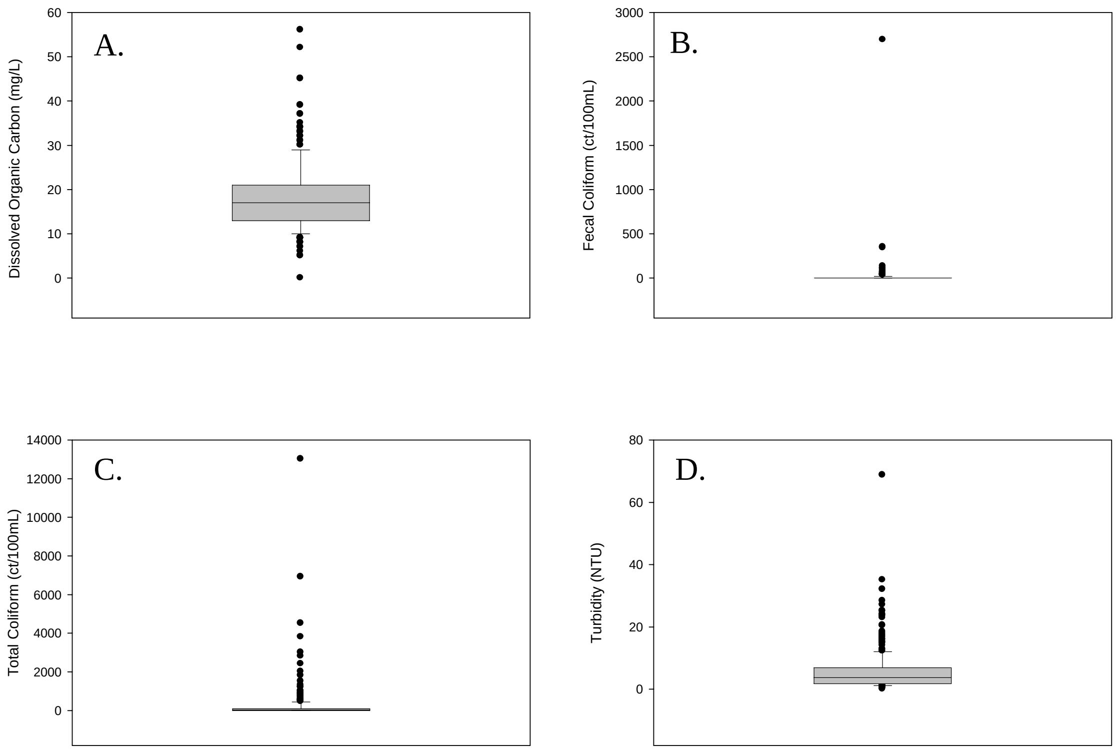

Figure B3 - Box plots demonstrating the variability of parameters tested in surface water (65 dugouts) with at least one sample exceeding the level suggested by the Saskatchewan Watershed Authority (A - Dissolved Organic Carbon) or; exceeding a *Municipal Drinking Water Standard* (B - Fecal Coliform Bacterial Count, C - Total Coliform Bacterial Count, D - Turbidity).

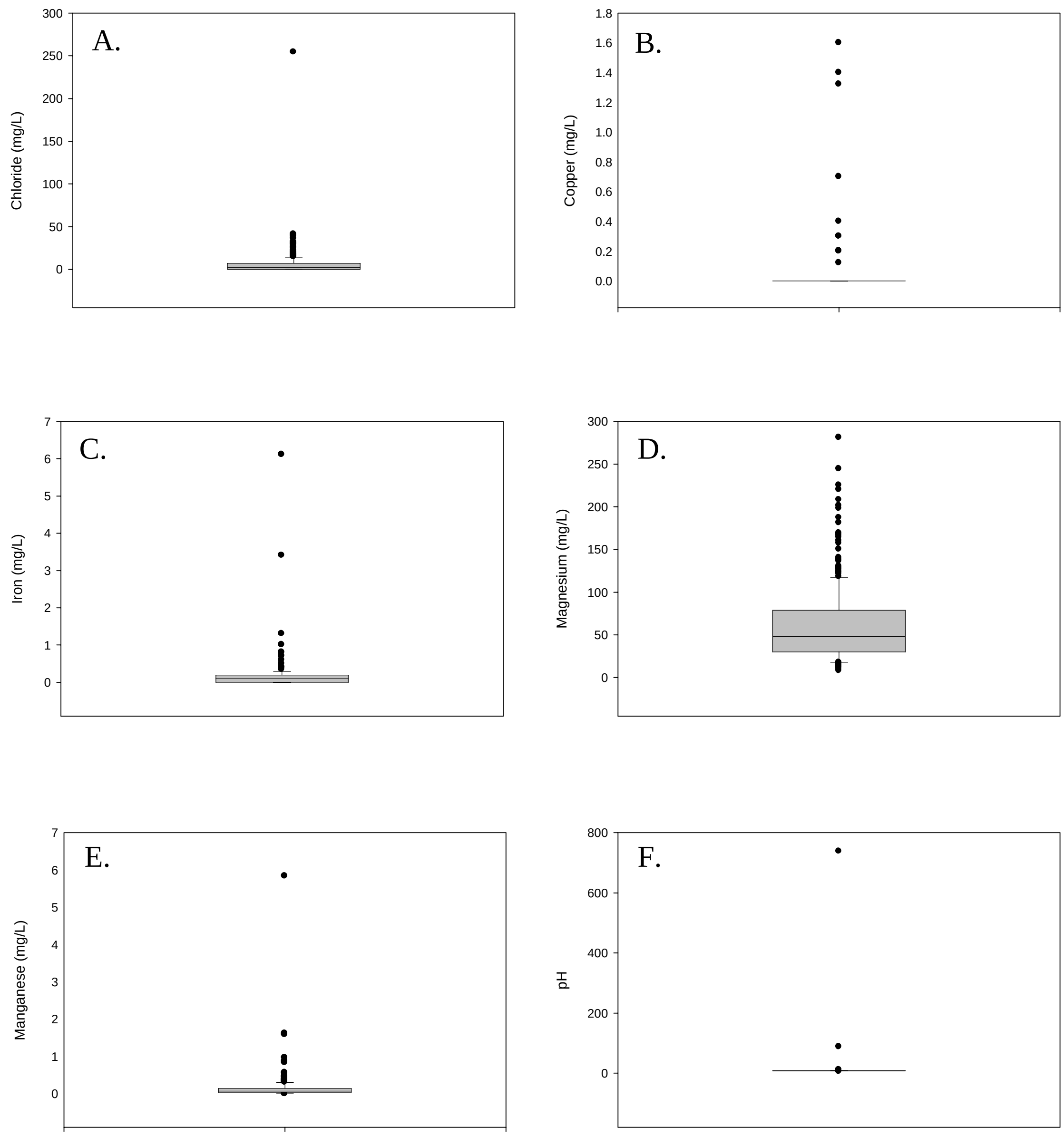

Figure B4.1 - Box plots demonstrating the variability of parameters tested in surface water (65 dugouts) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* objective (A - Chloride, B - Copper, C - Iron, D - Magnesium, E - Manganese, F - pH).

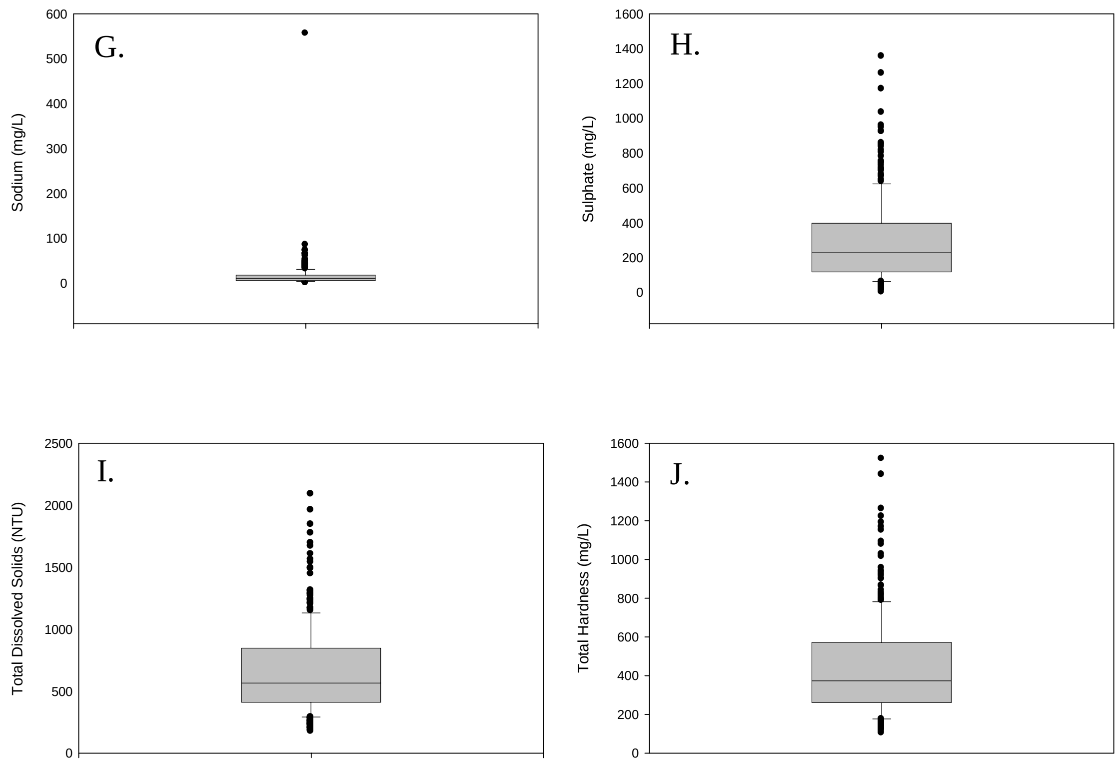

Figure B4.2 - Box plots demonstrating the variability of parameters tested in surface water (65 dugouts) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* (G - Sodium, H - Sulphate, I – Total Dissolved Solids, J – Total Hardness)

Appendix C

Bar Graphs of Paired Wells and Dugout Parameters with at Least Once Sample Exceeding a Municipal Water Quality Standard or Objective

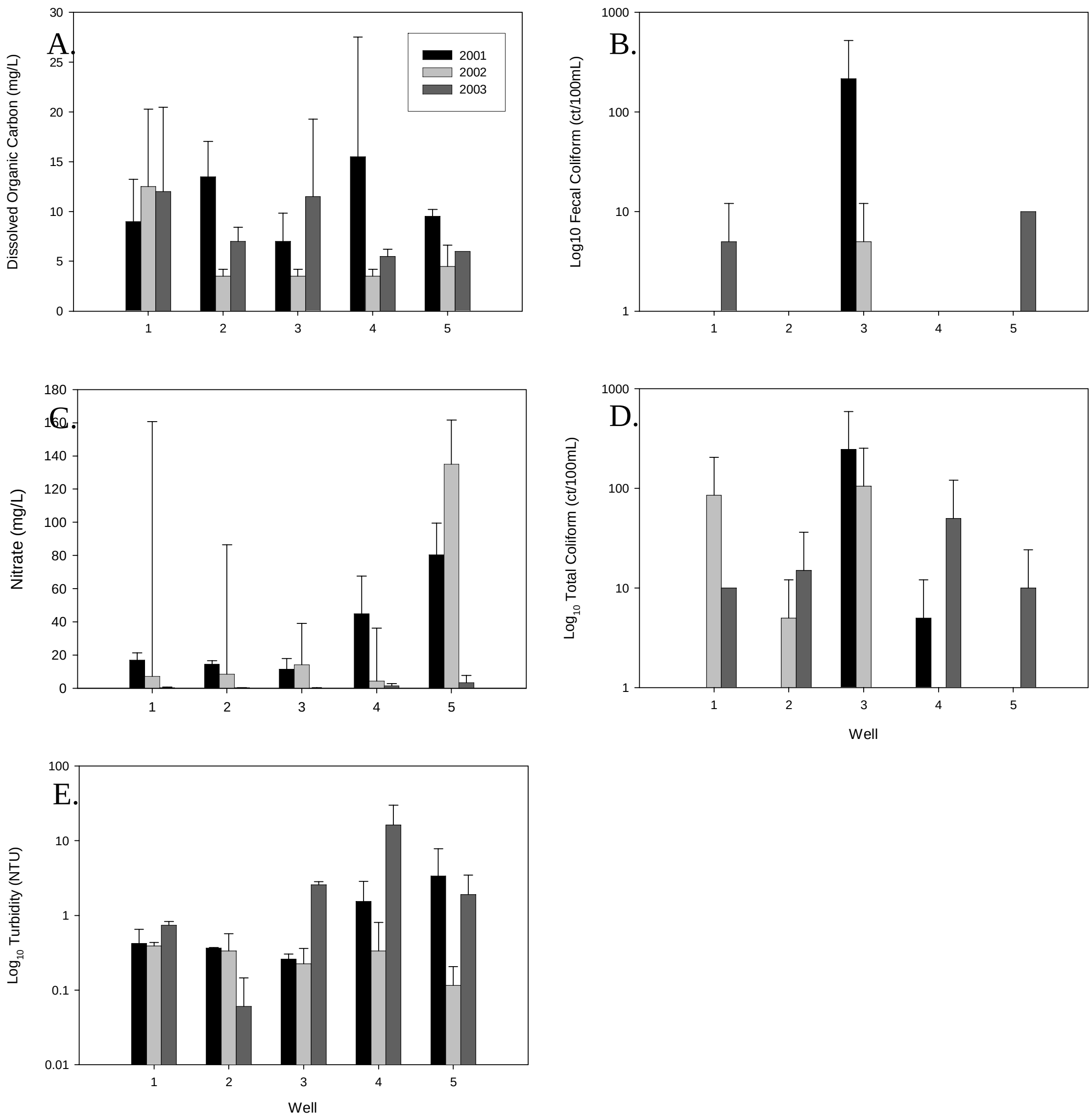

Figure C1 - Bar graphs of parameters tested in groundwater (paired wells only) with at least one sample exceeding the level suggested by the Saskatchewan Watershed Authority compared by year that the samples were taken (A - Dissolved Organic Carbon) or; exceeding a *Municipal Drinking Water Standard* (B - Fecal Coliform Bacterial Count, C - Nitrate, D - Total Coliform Bacterial Count, E - Turbidity). Data are presented as the mean ± standard deviation. Note: log scale for Fecal Coliform Bacteria Count, Total Coliform Bacterial Count and Turbidity.

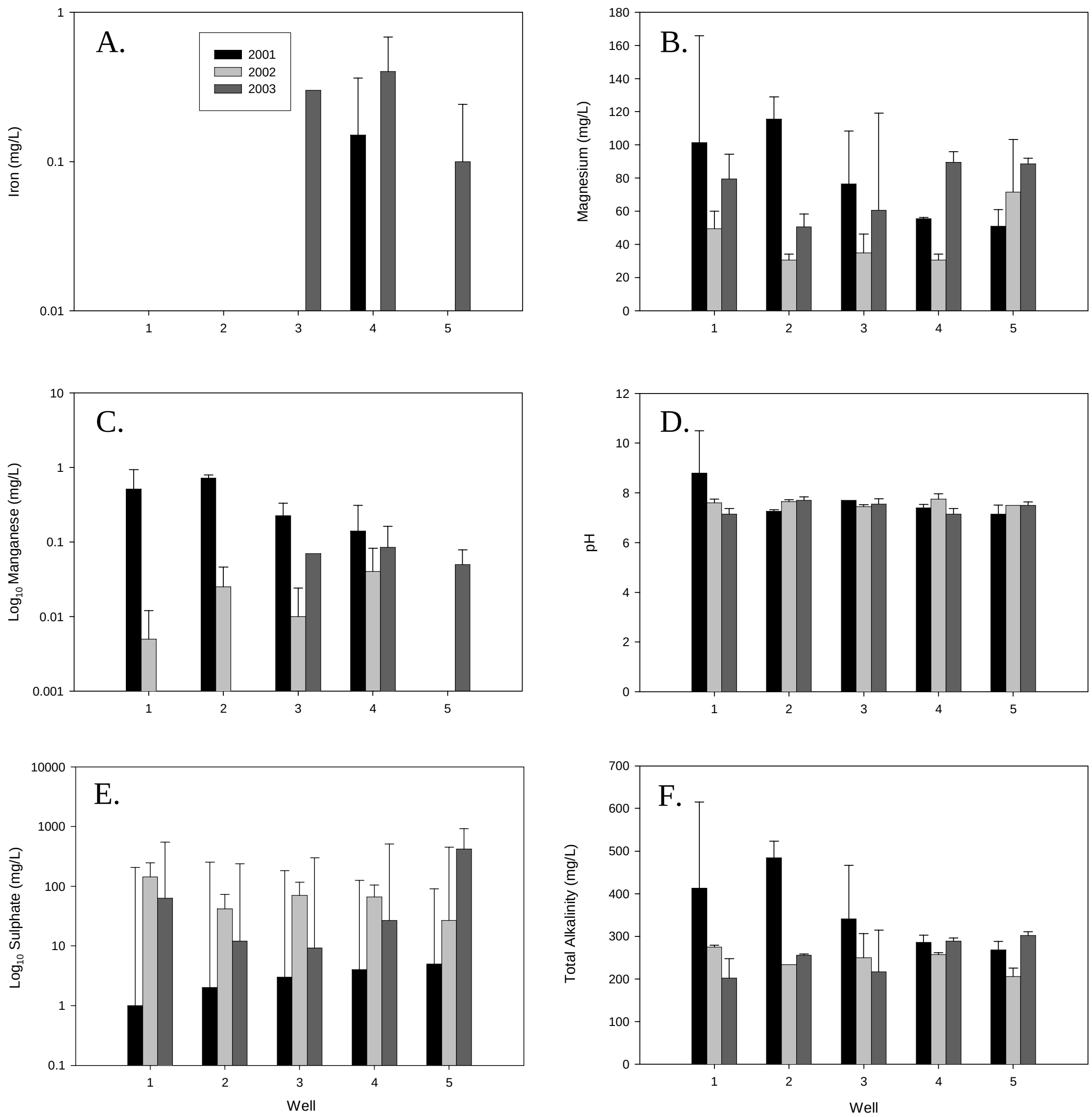

Figure C2.1 - Bar graphs of parameters tested in groundwater (paired wells only) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* compared by year that the samples were taken (A - Iron, B - Magnesium, C - Manganese, D - pH, E - Sulphate, F - Total Alkalinity). Data are presented as the mean ± standard deviation. Note: log scale for Iron, Manganese and Sulphate.

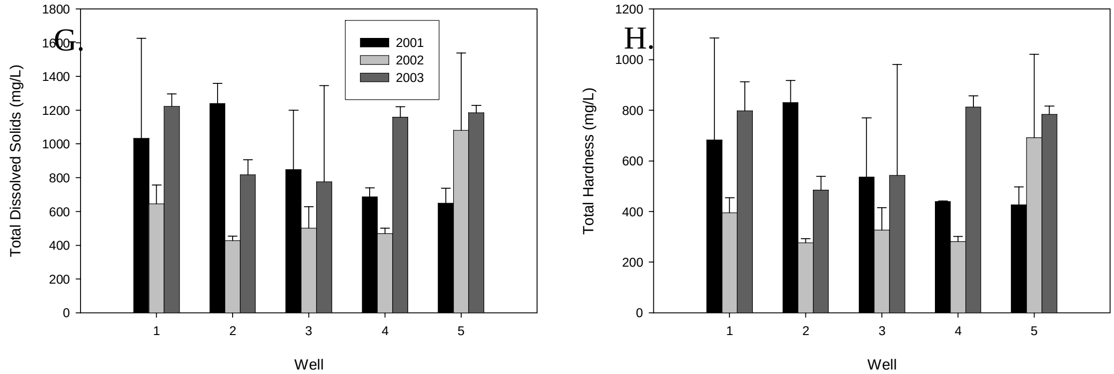

Figure C2.2 - Bar graphs of parameters tested in groundwater (paired wells only) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* compared by year that the samples were taken (G - Total Dissolved Solids, H - Total Hardness). Data are presented as the mean ± standard deviation.

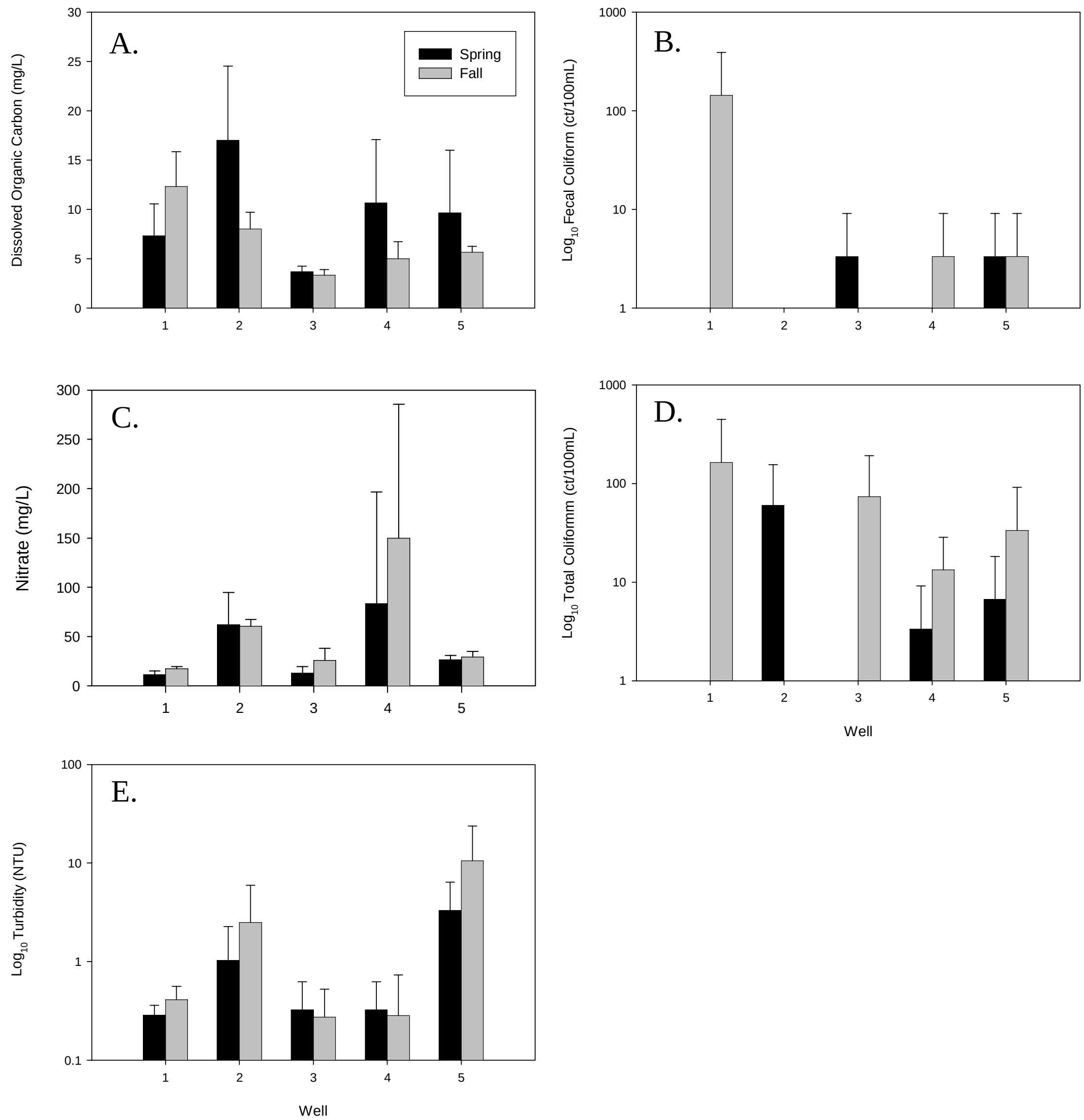

Figure C3 - Bar graphs of parameters tested in groundwater (paired wells only) with at least one sample exceeding the level suggested by the Saskatchewan Watershed Authority compared by the season that the samples were taken (A - Dissolved Organic Carbon) or; exceeding a *Municipal Drinking Water Standard* (B - Fecal Coliform Bacterial Count, C - Nitrate, D - Total Coliform Bacterial Count, E - Turbidity). Data are presented as the mean ± standard deviation. Note: log scale for Fecal Coliform Bacteria Count, Total Coliform Bacterial Count and Turbidity.

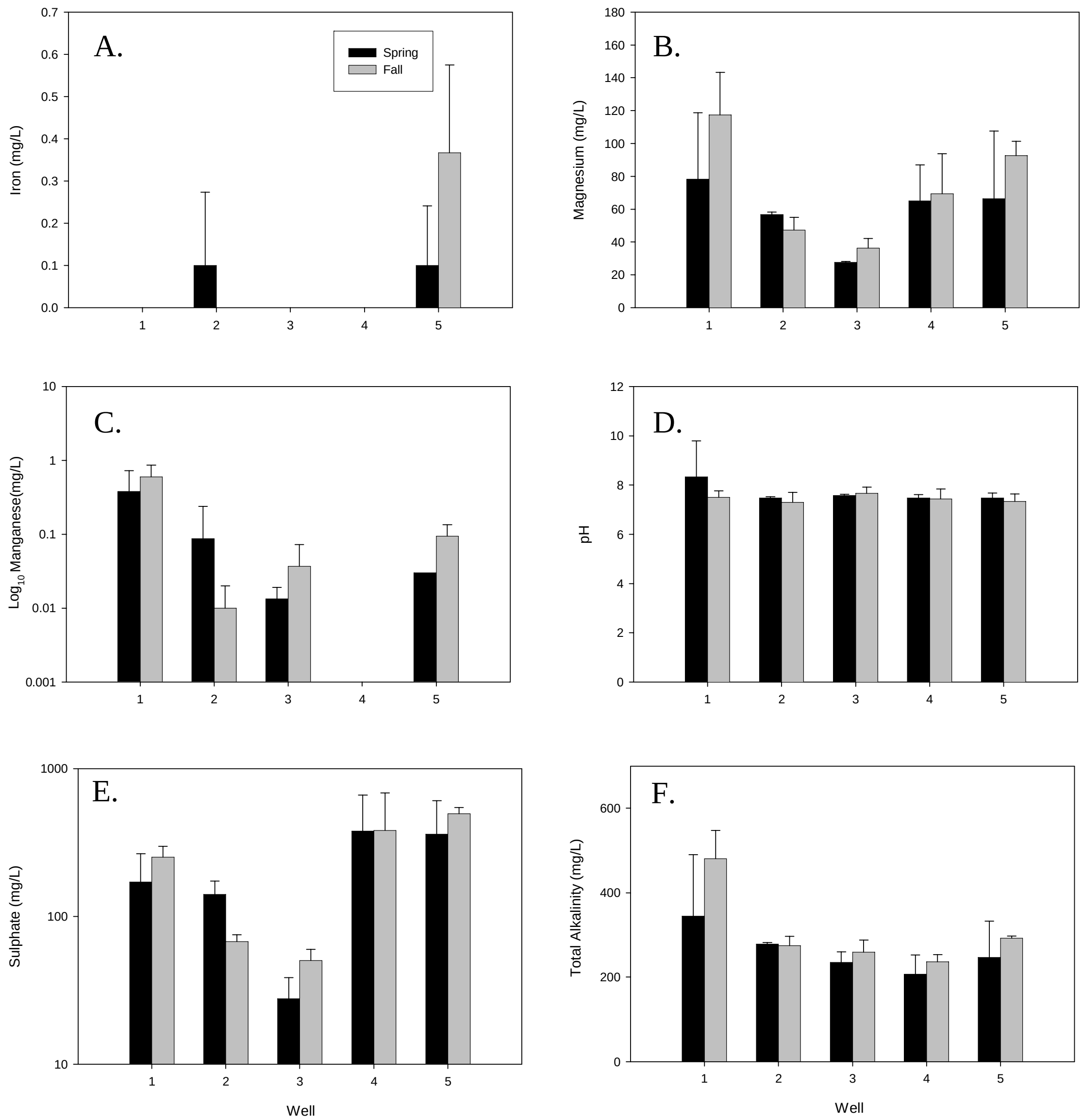

Figure C4.1 - Bar graphs of parameters tested in groundwater (paired wells only) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* compared by the season that the samples were taken (A - Iron, B - Magnesium, C - Manganese, D - pH, E - Sulphate, F - Total Alkalinity). Data are presented as the mean ± standard deviation. Note: log scale for Iron, Manganese and Sulphate.

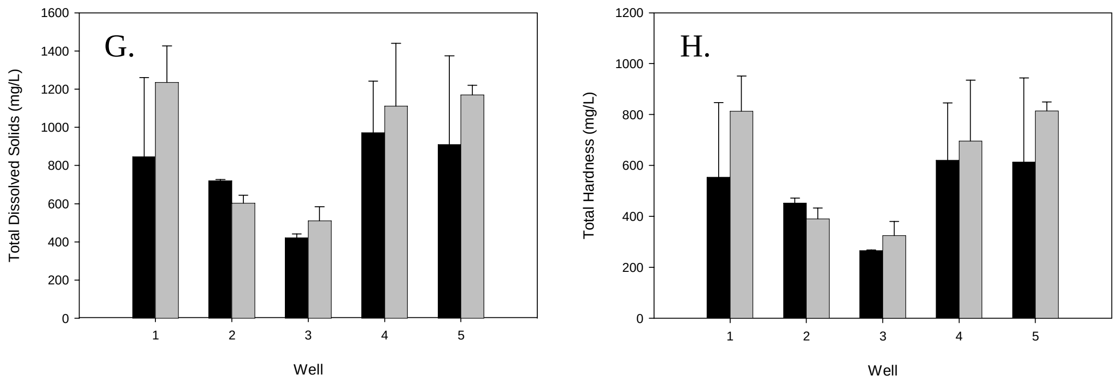

Figure C4.2 - Bar graphs of parameters tested in groundwater (paired wells only) with at least one sample exceeding the *Municipal Drinking Water Aesthetic Objective* compared by year that the samples were taken (G - Total Dissolved Solids, H - Total Hardness). Data are presented as the mean ± standard deviation.

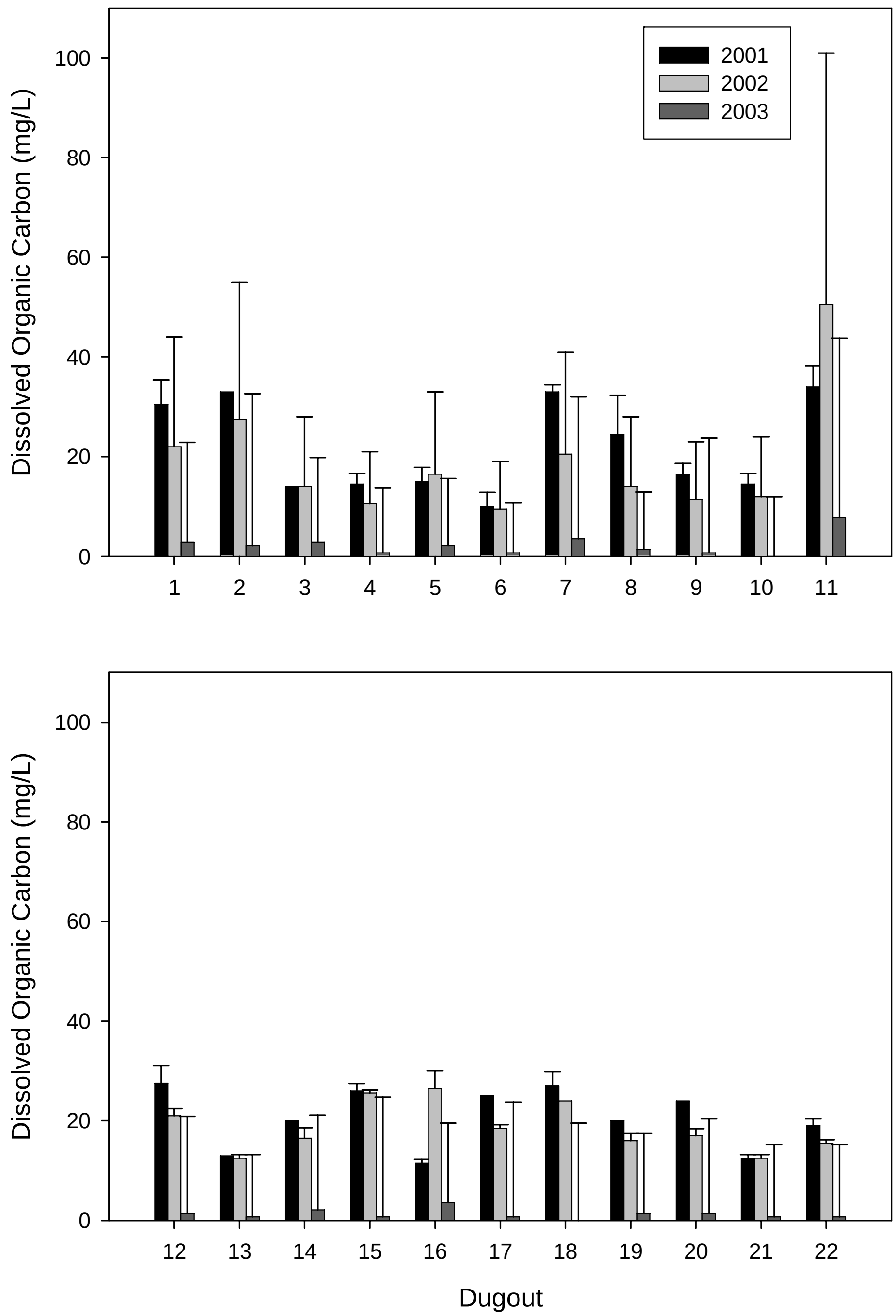

Figure C5 - Dissolved Organic Carbon of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. All of the dugouts exceeded the 5 mg/L level suggested by the Saskatchewan Watershed Authority at least once during the sampling period. Data are presented as mean ± standard deviation.

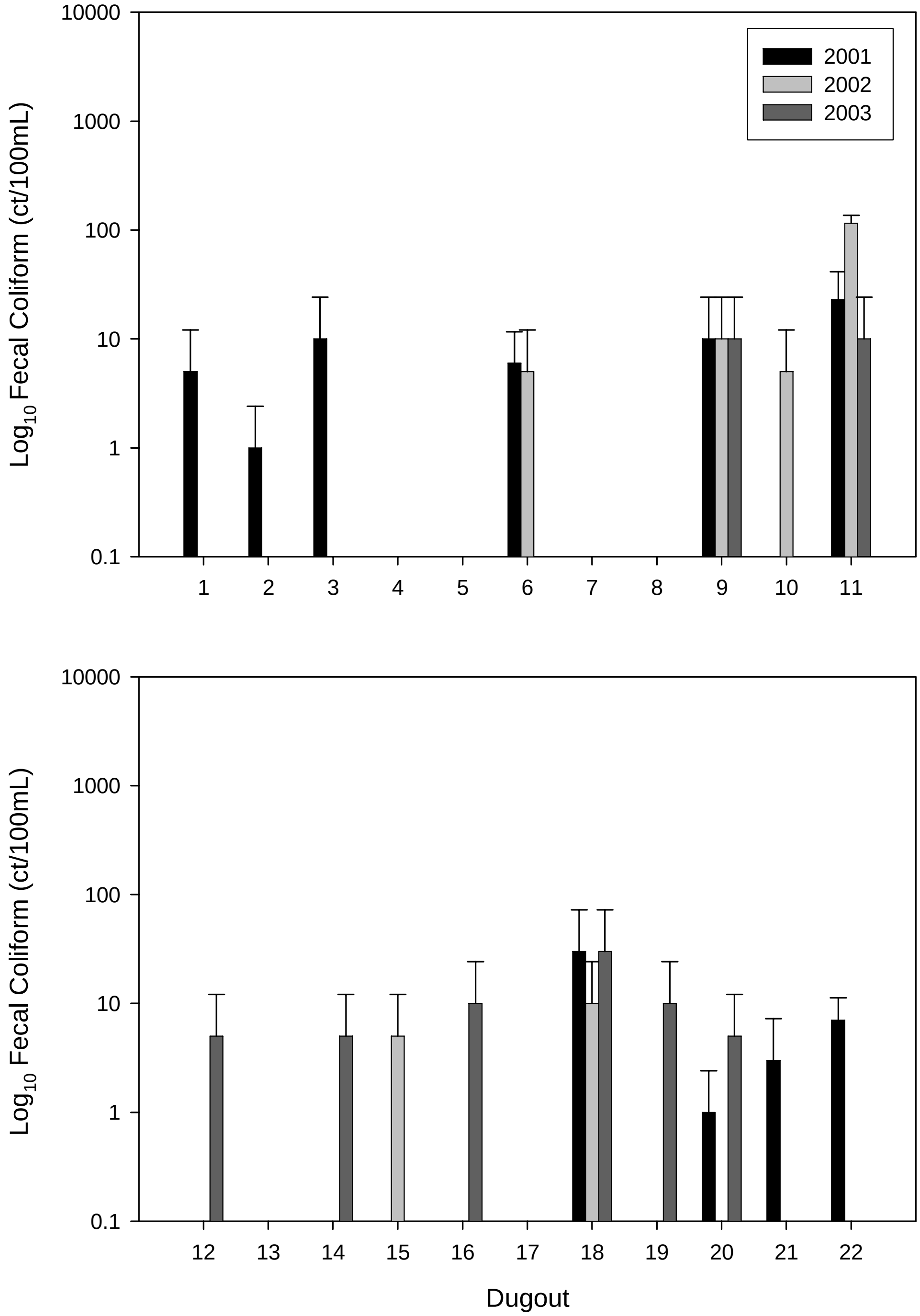

Figure C6 - Fecal Coliform Bacterial Count of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Standard* is 0 ct/100mL. Data are presented as mean ± standard deviation. Note: log scale.

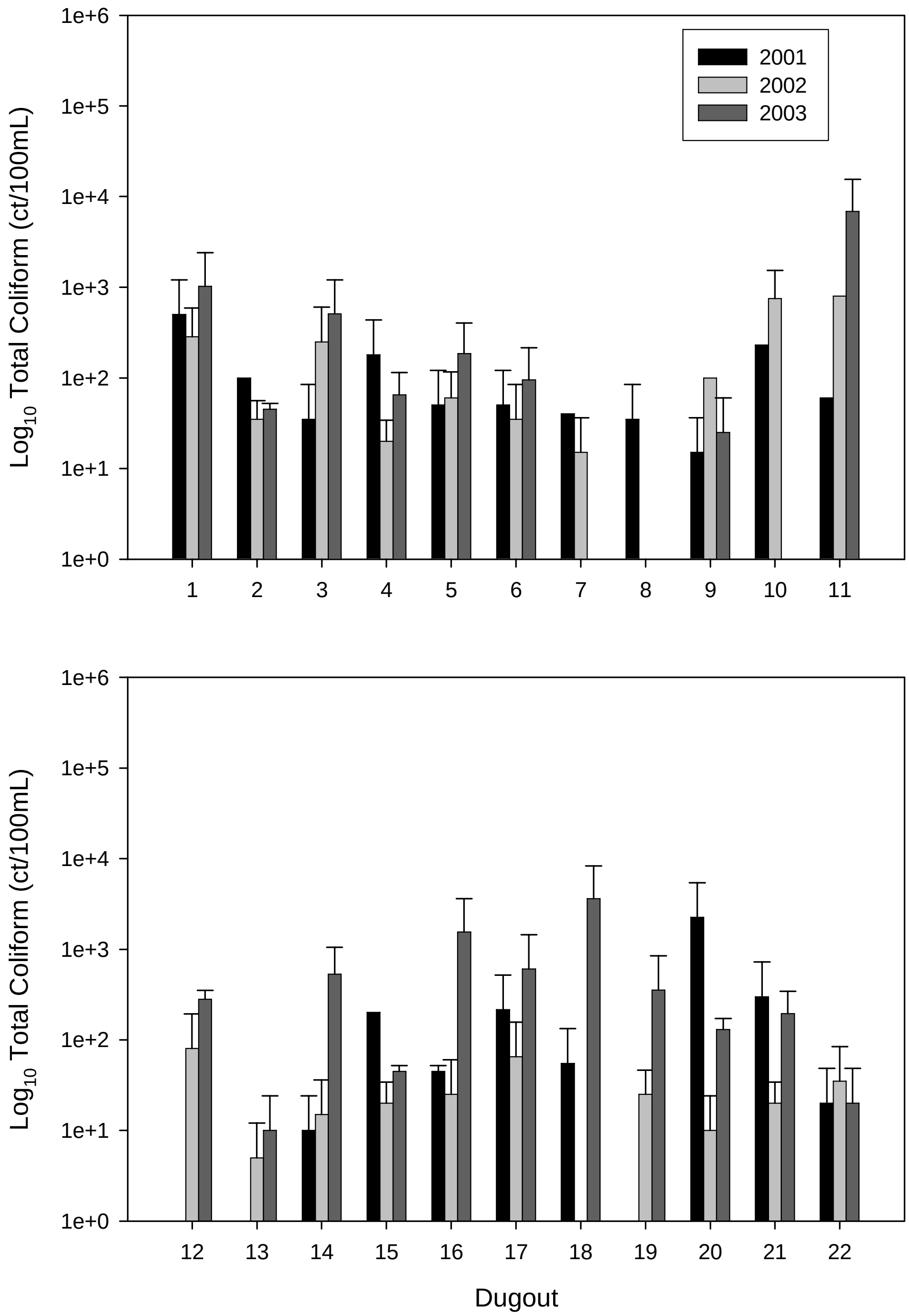

Figure C7 - Total Coliform Bacterial Count of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. *Municipal Drinking Water Standard* is 0 ct/100mL. Data are presented as mean ± standard deviation. Note log scale.

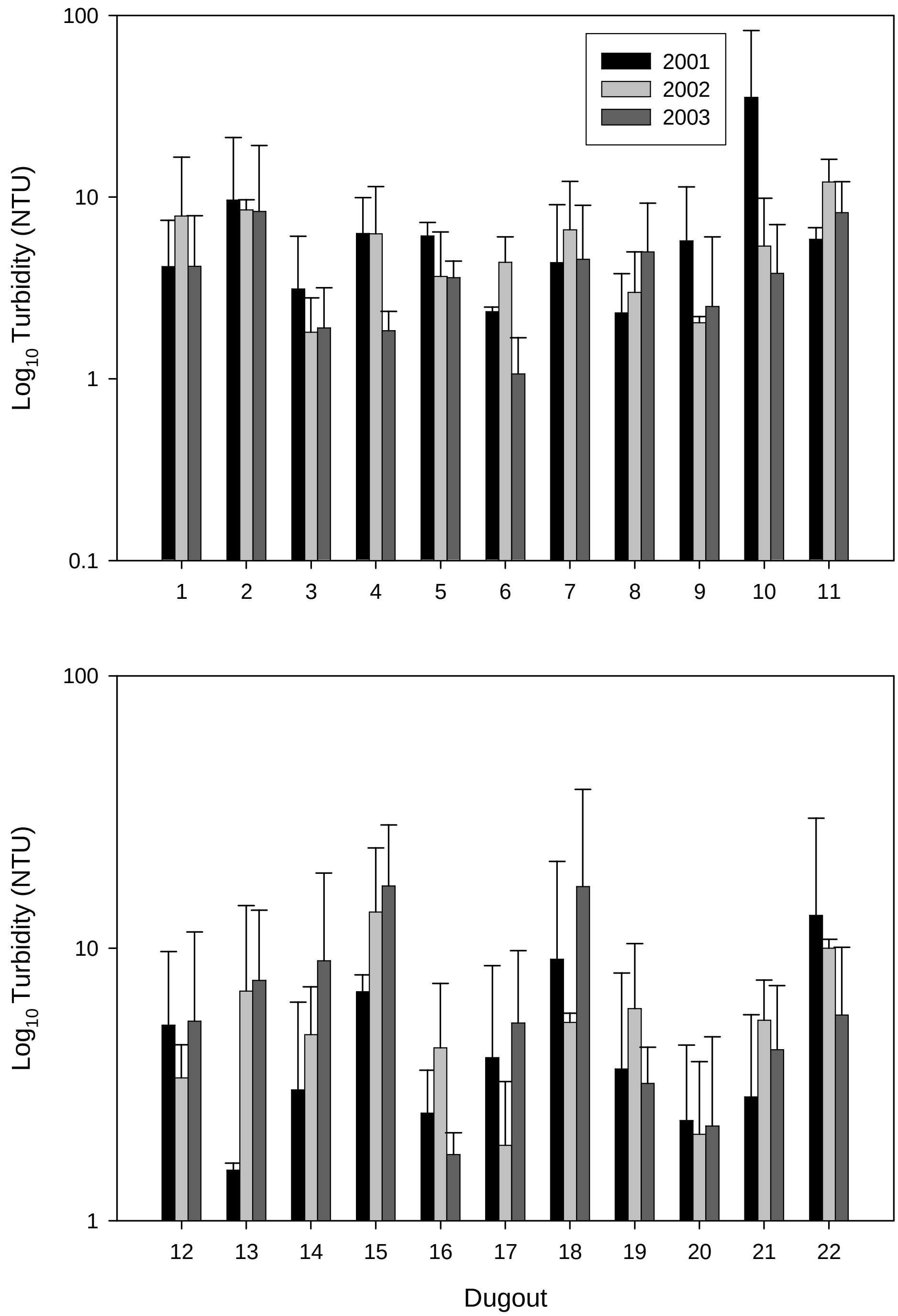

Figure C8 - Turbidity of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Standard* is 1 NTU. Data are presented as mean ± standard deviation. Note: log scale.

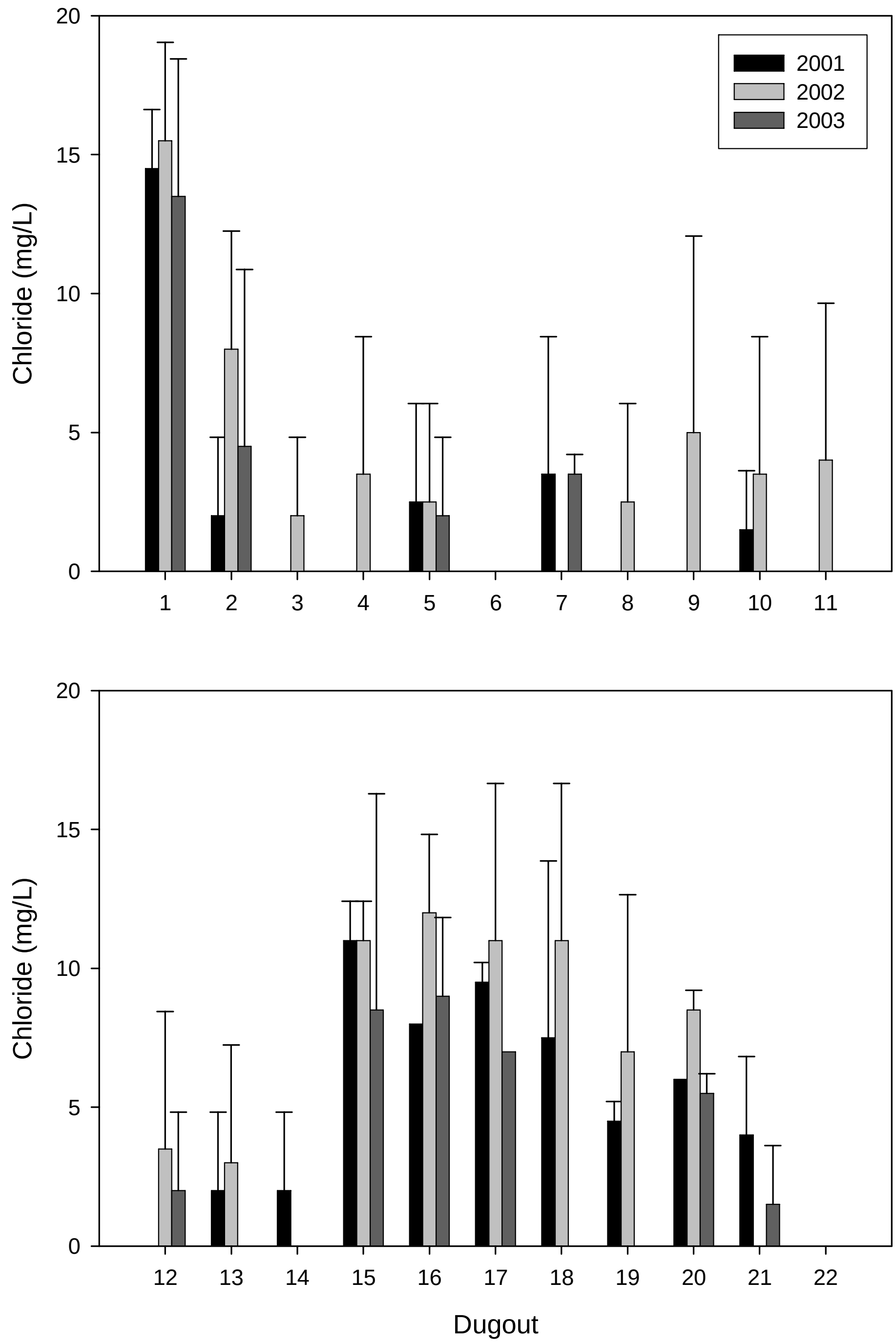

Figure C9 - Chloride concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 250 mg/L. Data are presented as mean ± standard deviation.

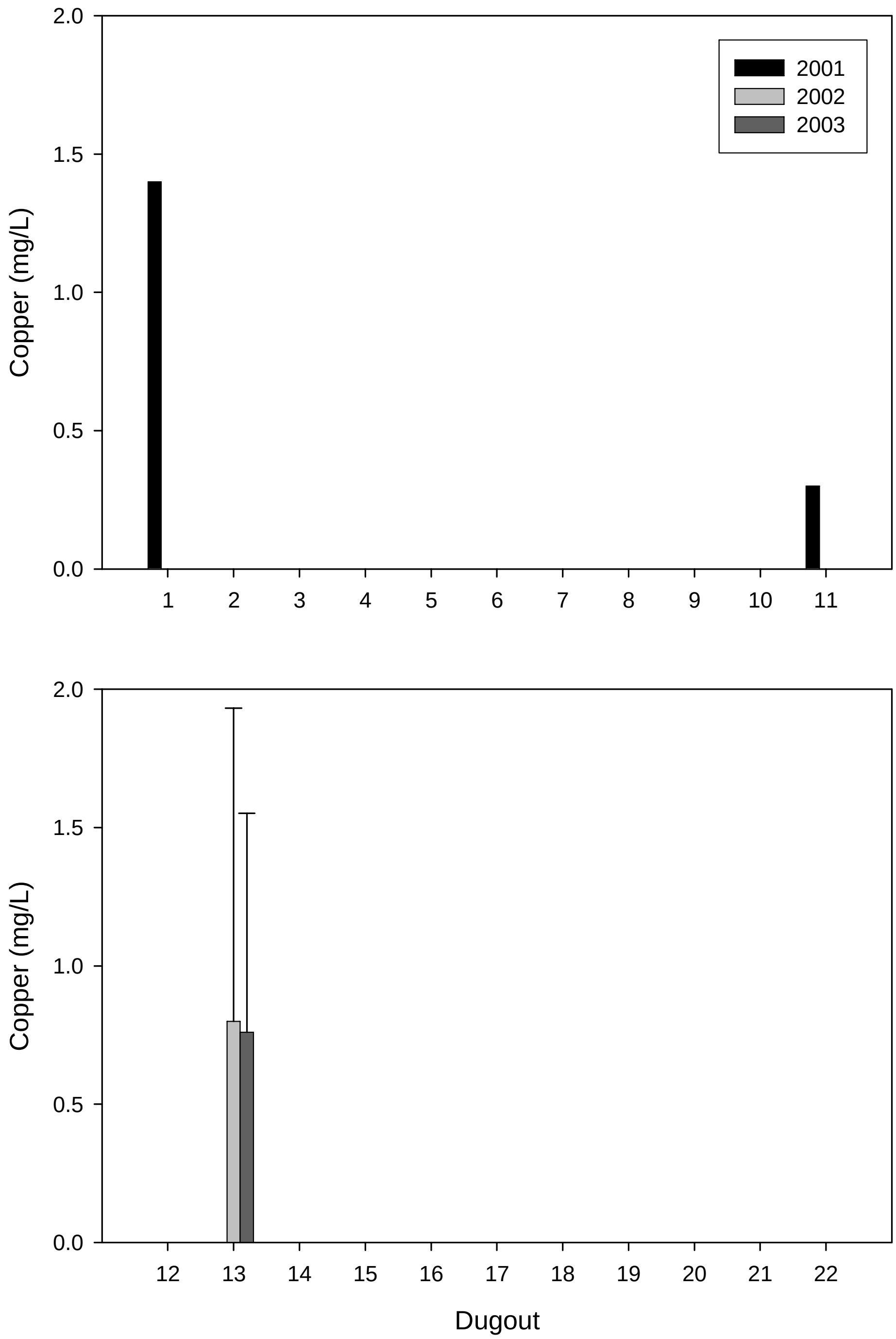

Figure C10 - Copper concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 1 mg/L. Data are presented as mean ± standard deviation.

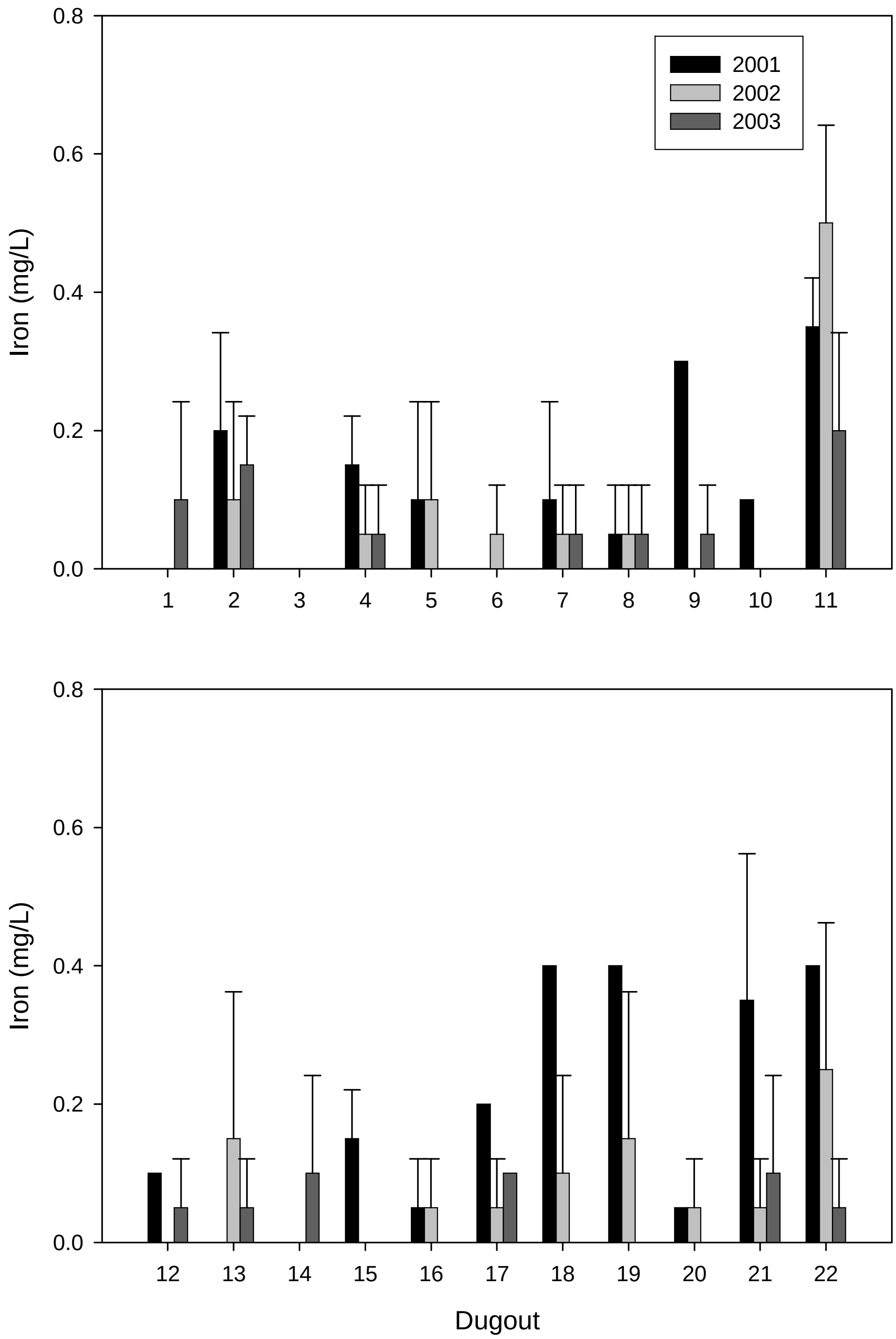

Figure C11 - Iron concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 0.3 mg/L. Data are presented as mean ± standard deviation.

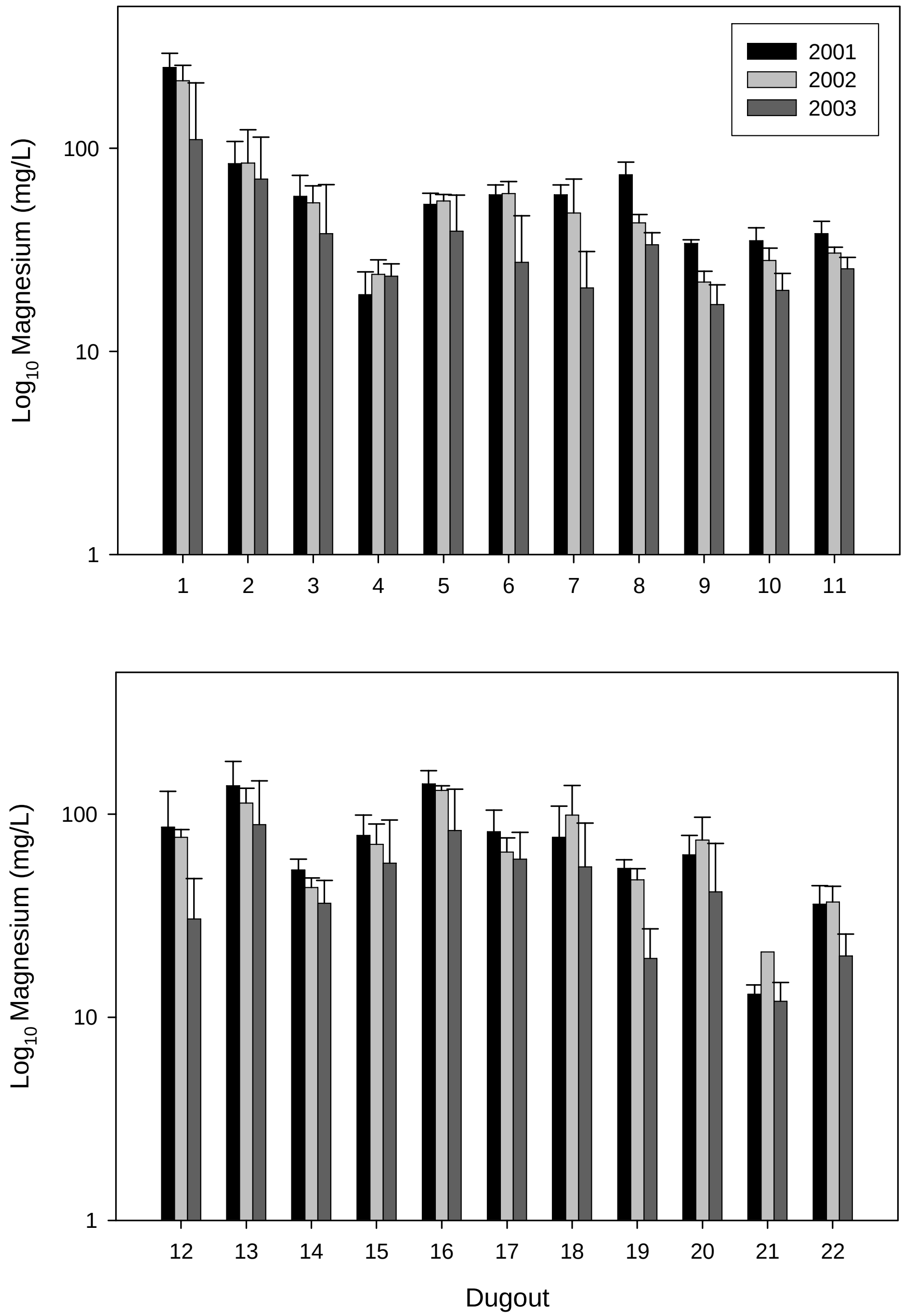

Figure C12 - Magnesium concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 200 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

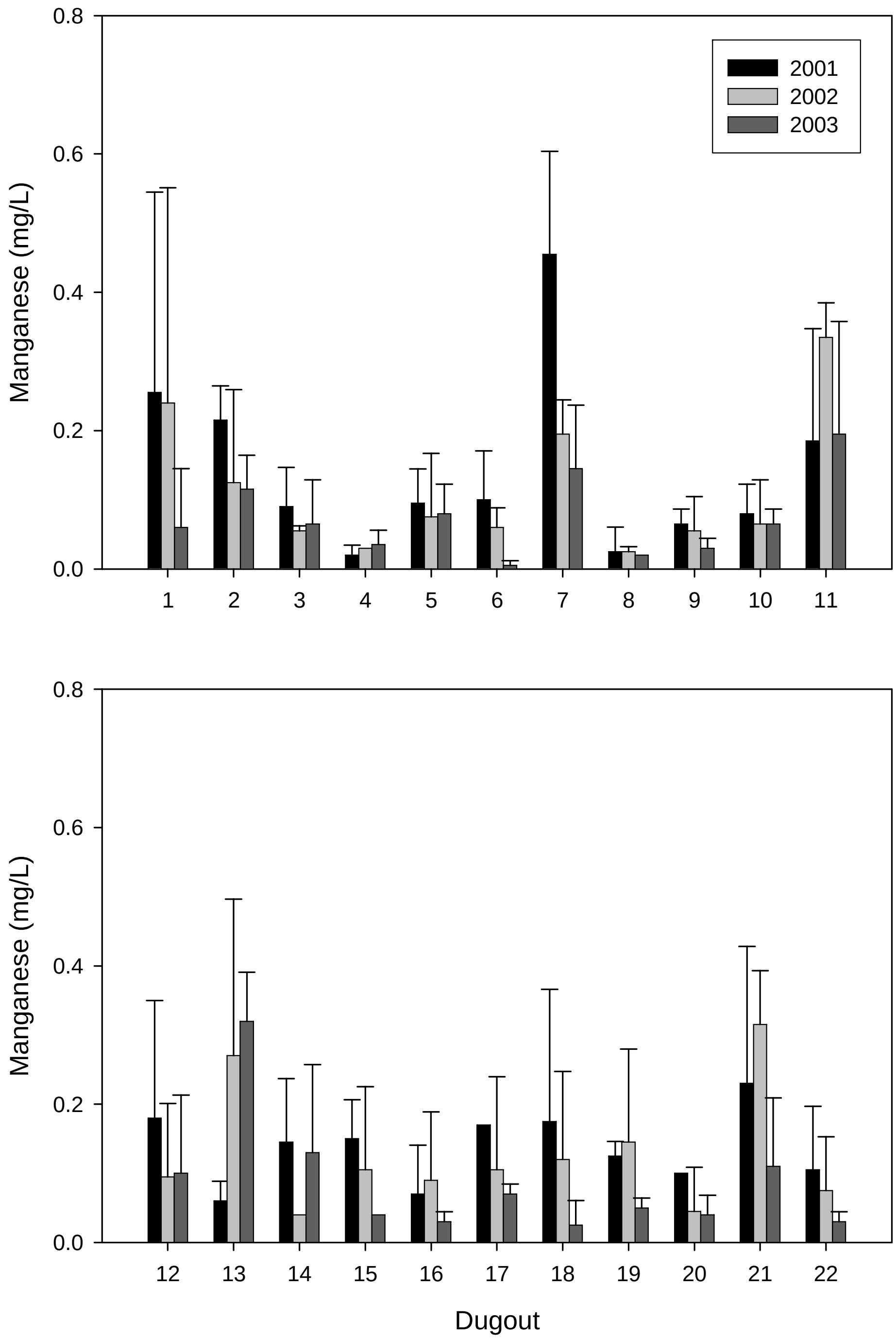

Figure C13 - Manganese concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 0.05 mg/L. Data are presented as mean ± standard deviation.

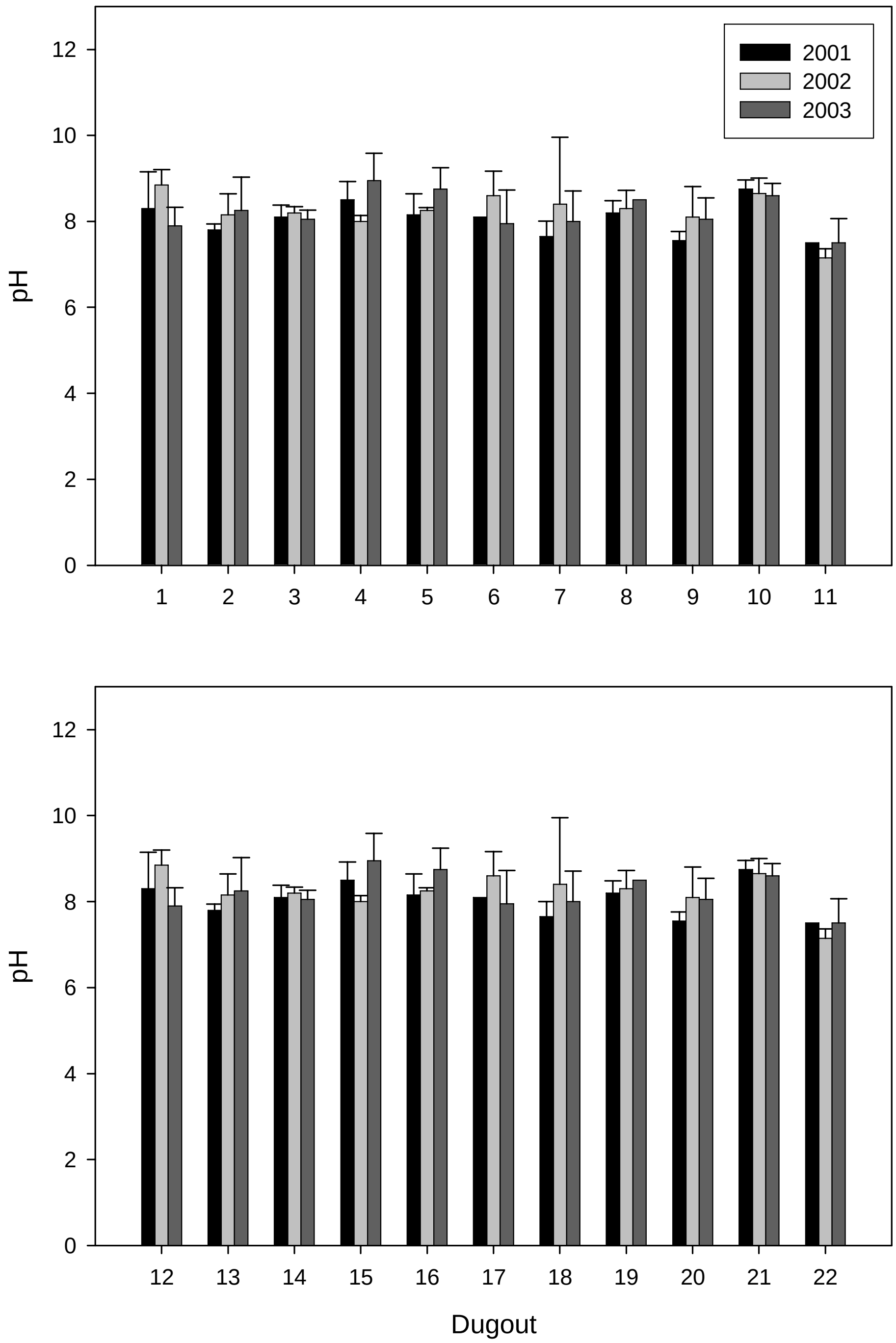

Figure C14 - The 22 dugouts with paired seasonal data pH, compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is a range from 6.5-9.0. Data are presented as mean ± standard deviation.

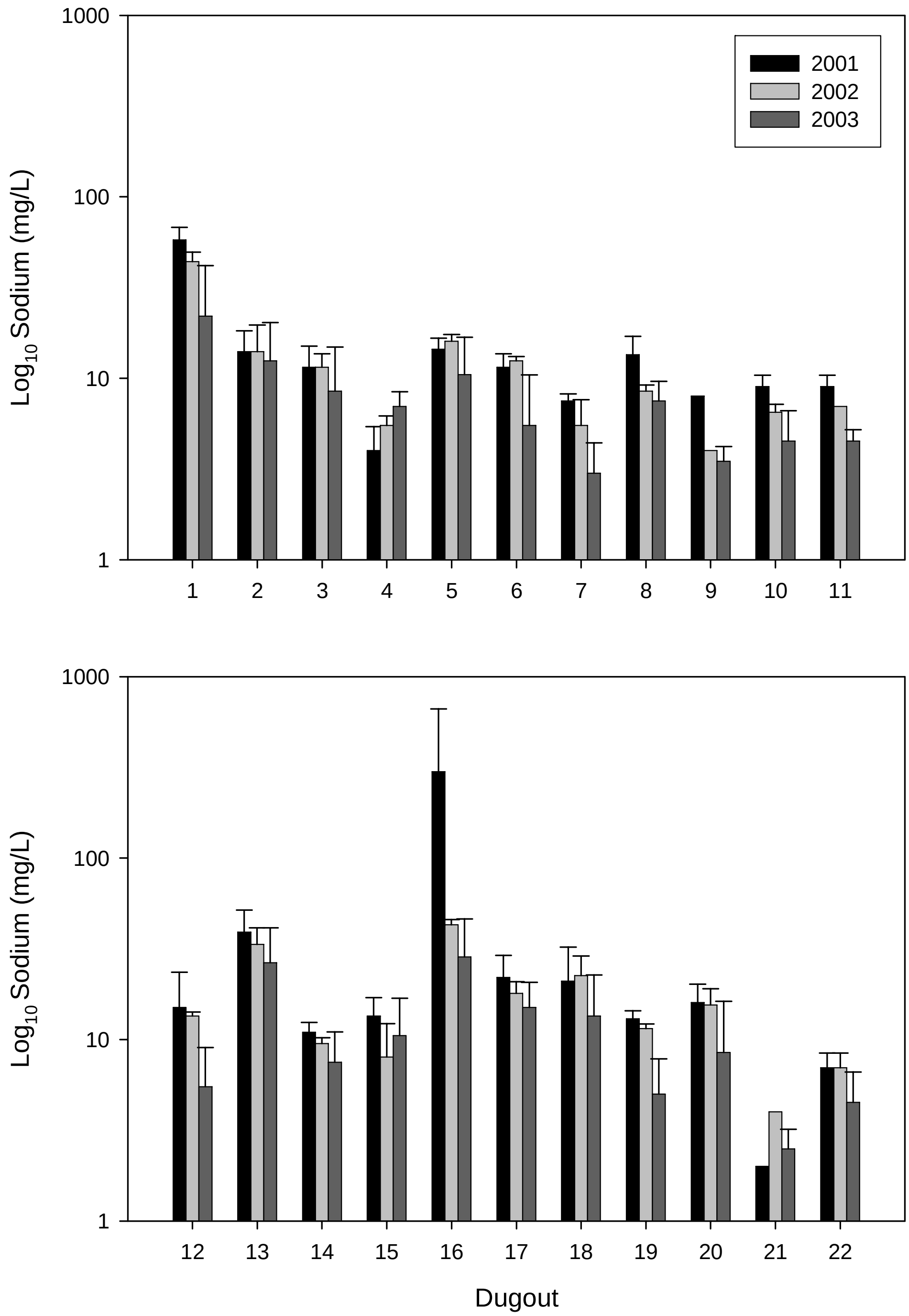

Figure C15 - Sodium concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 300 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

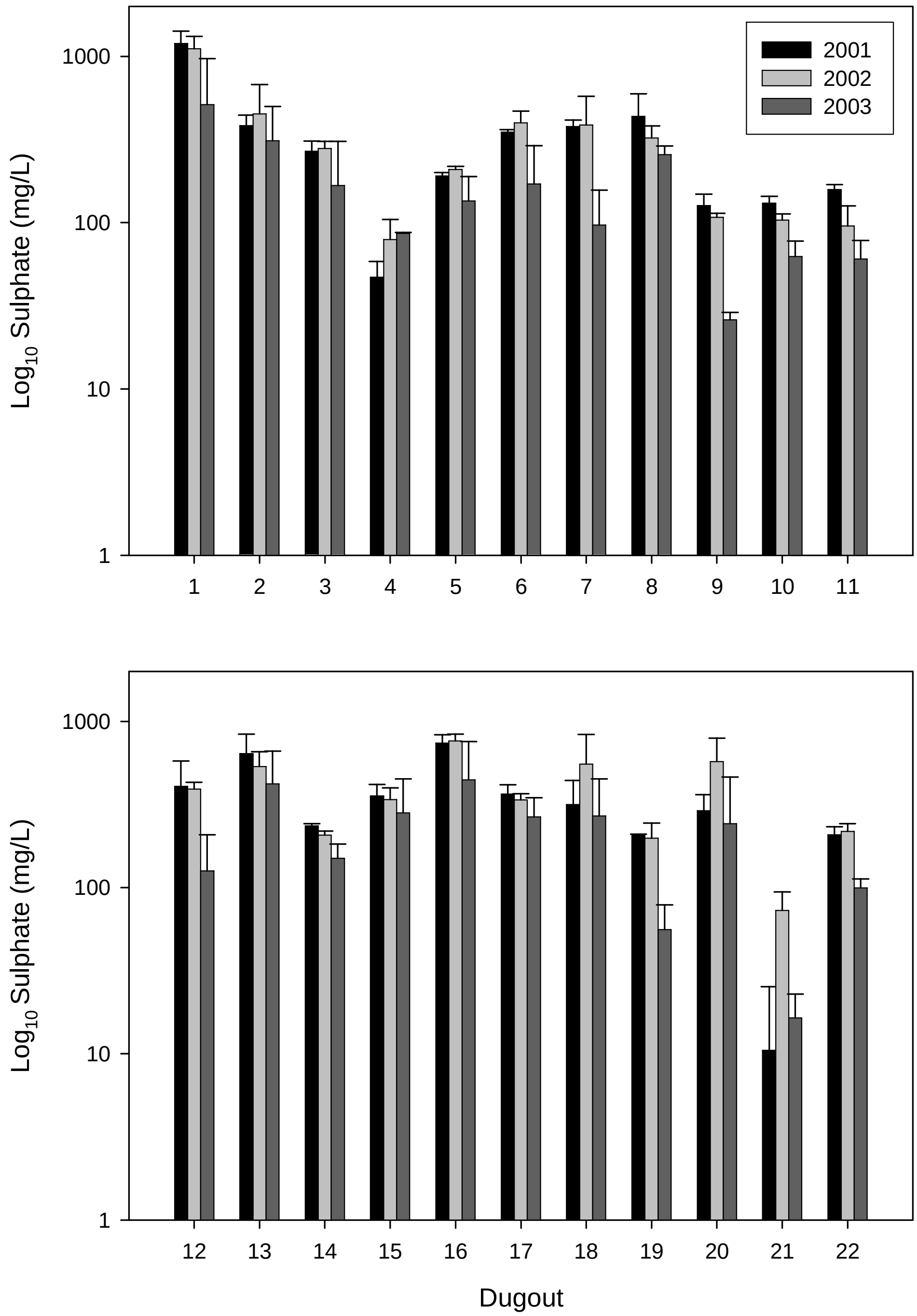

Figure C16 - Sulphate concentration of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 500 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

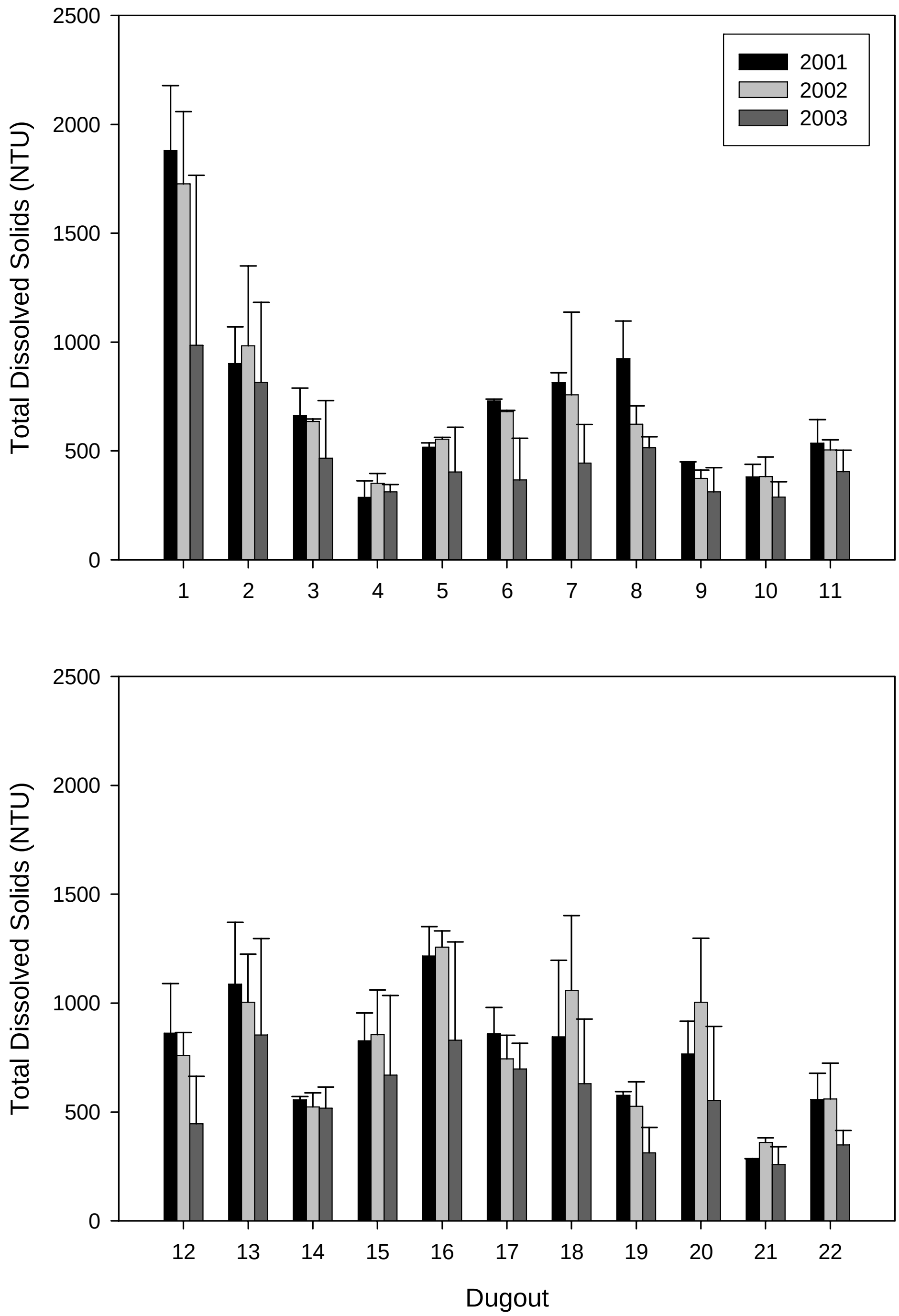

Figure C17 - Total Dissolved Solids of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is less than 1,500 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

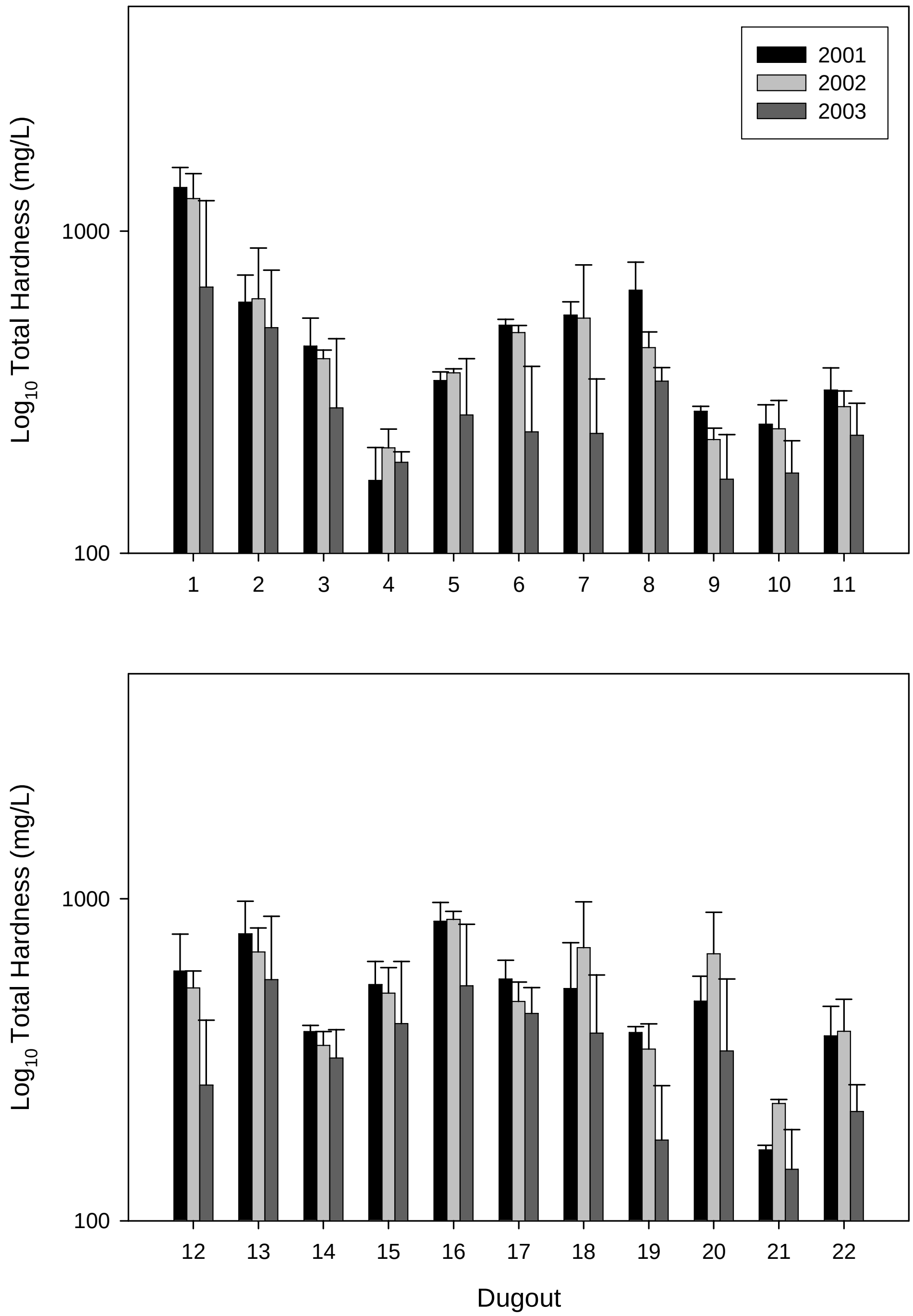

Figure C18 - Total Hardness of the 22 dugouts with paired seasonal data compared by the year that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is less than 800 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

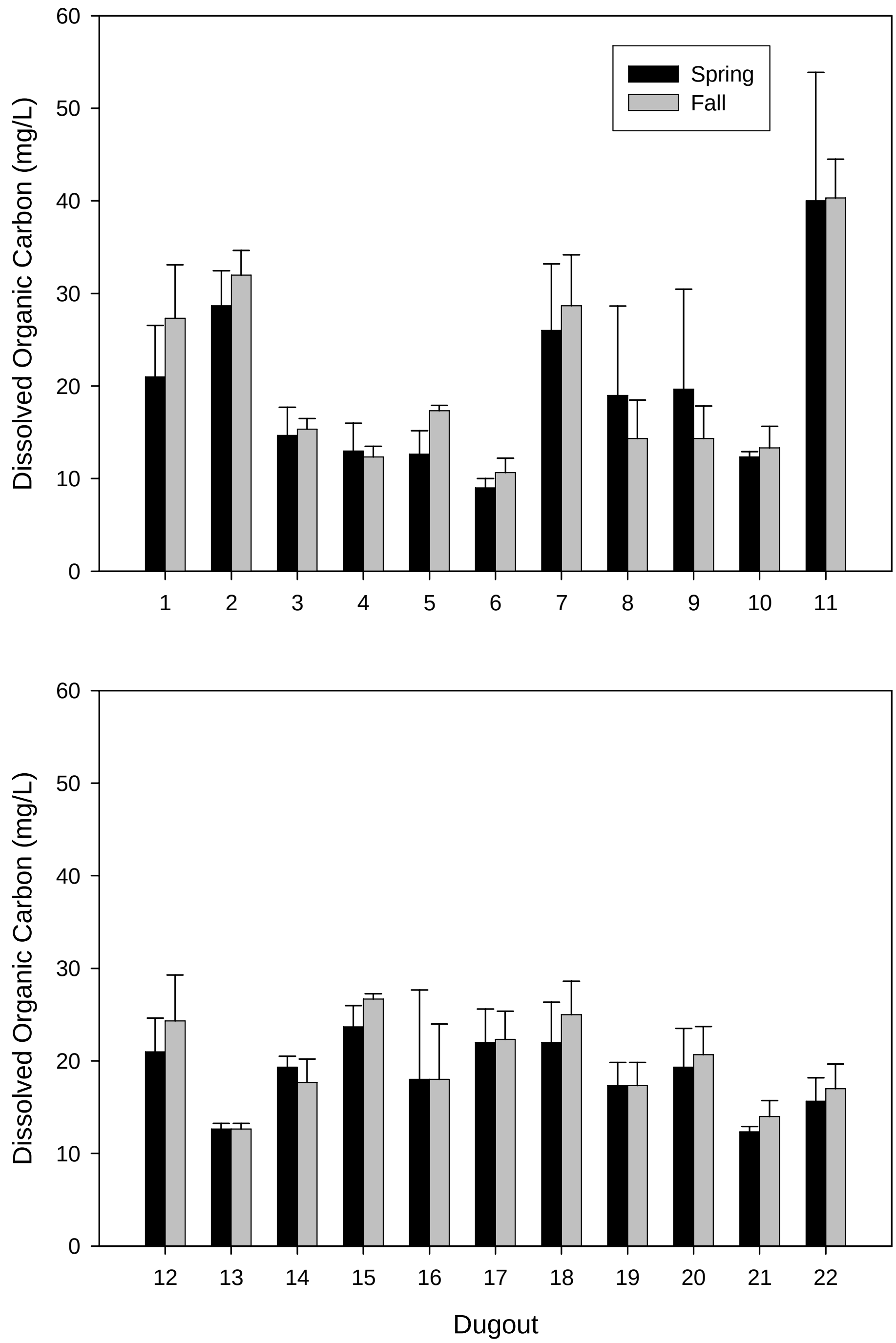

Figure C19 - Dissolved Organic Carbon of the 22 dugouts with paired seasonal data compared the season that the sample was taken. All of the dugouts exceeded the 5 mg/L level suggested by the Saskatchewan Watershed Authority at least once during the sampling period. Data are presented as mean ± standard deviation.

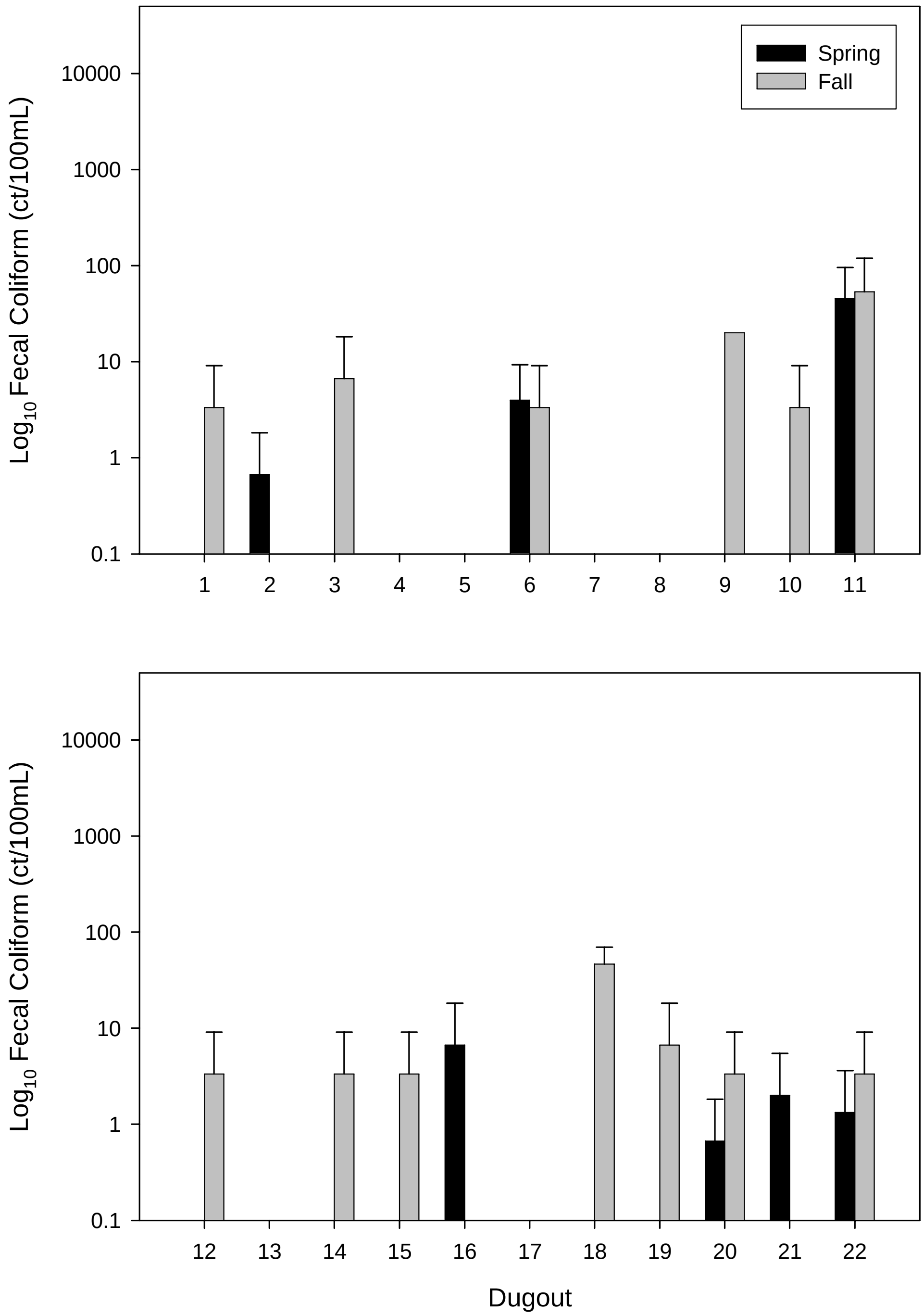

Figure C20 - Fecal Coliform Bacterial Count of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Standard* is 0 ct/100mL. Data are presented as mean ± standard deviation. Note: log scale.

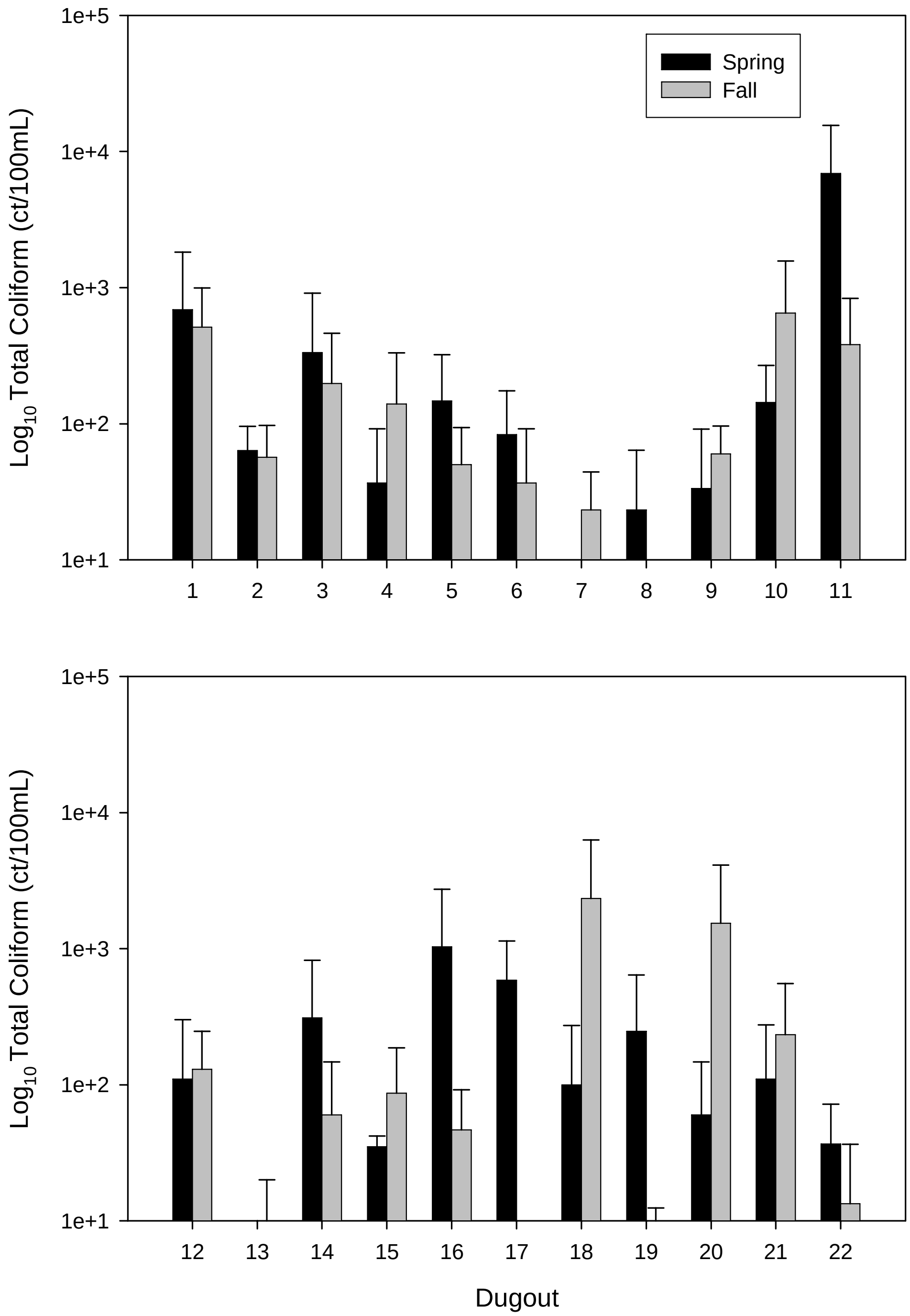

Figure C21 - Total Coliform Bacterial Count of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Standard* is 0 ct/100mL. Data are presented as mean ± standard deviation. Note log scale.

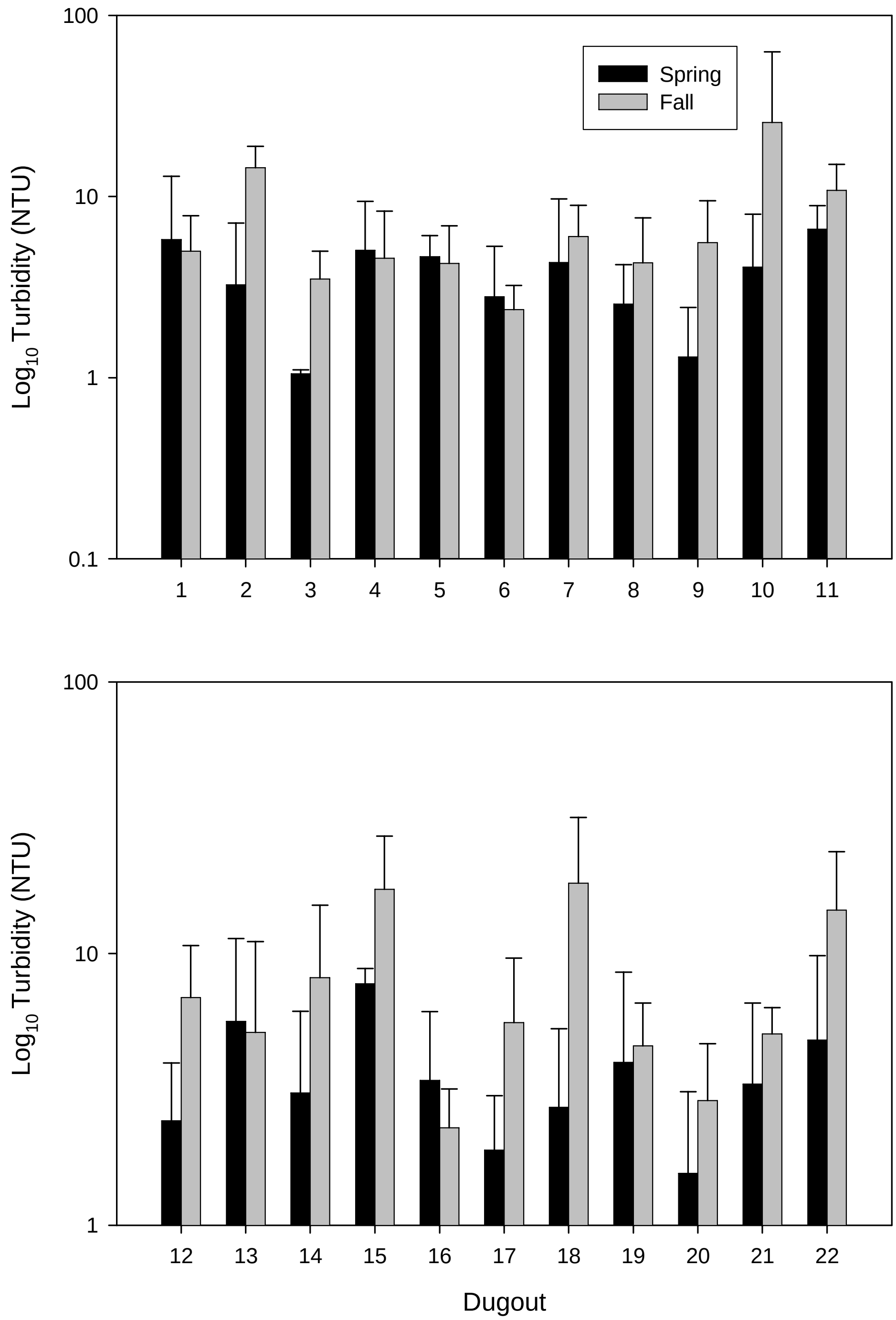

Figure C22 - Turbidity of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Standard* is 1 NTU. Data are presented as mean ± standard deviation. Note: log scale.

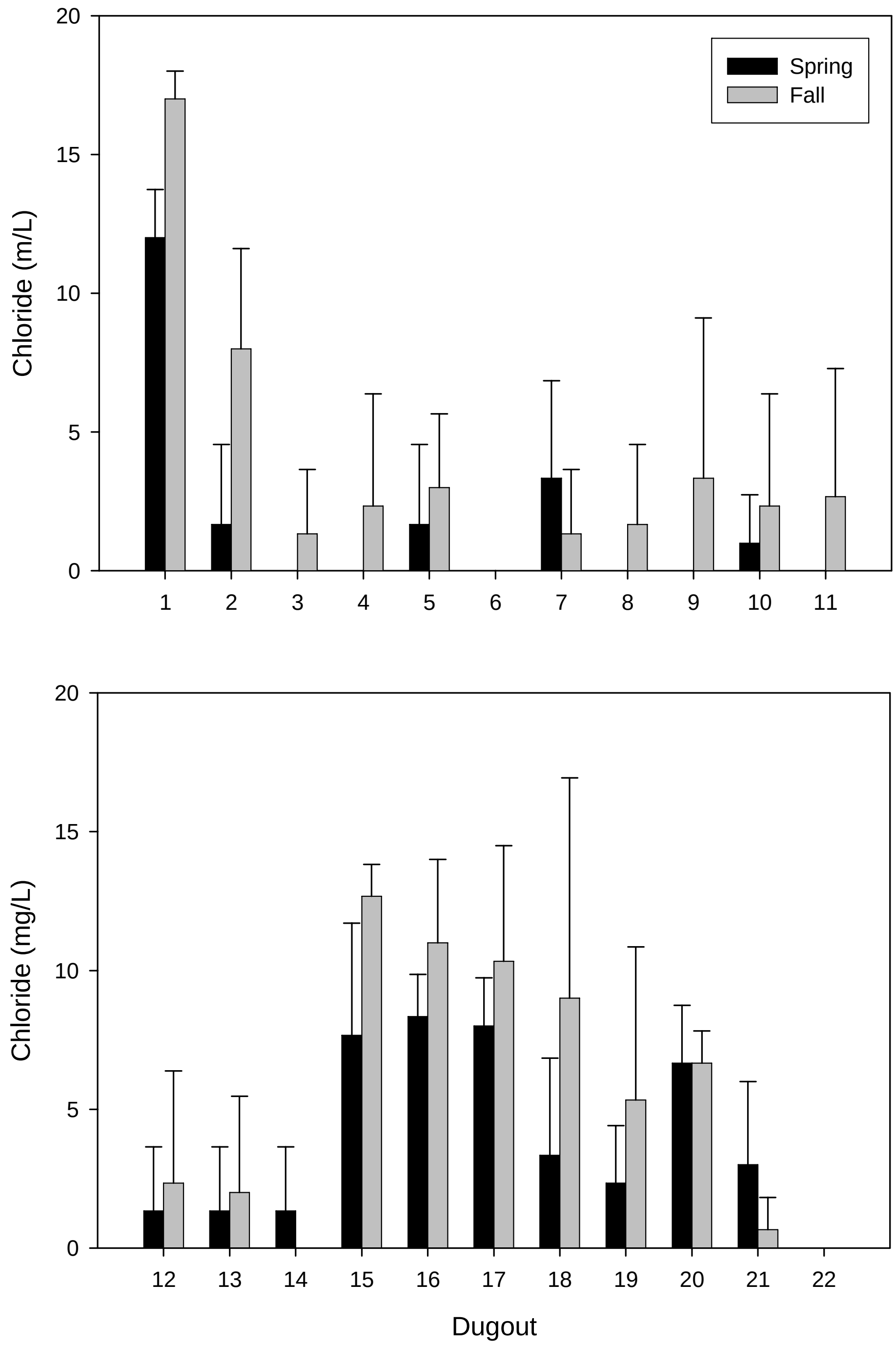

Figure C23 - Chloride concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 250 mg/L. Data are presented as mean ± standard deviation.

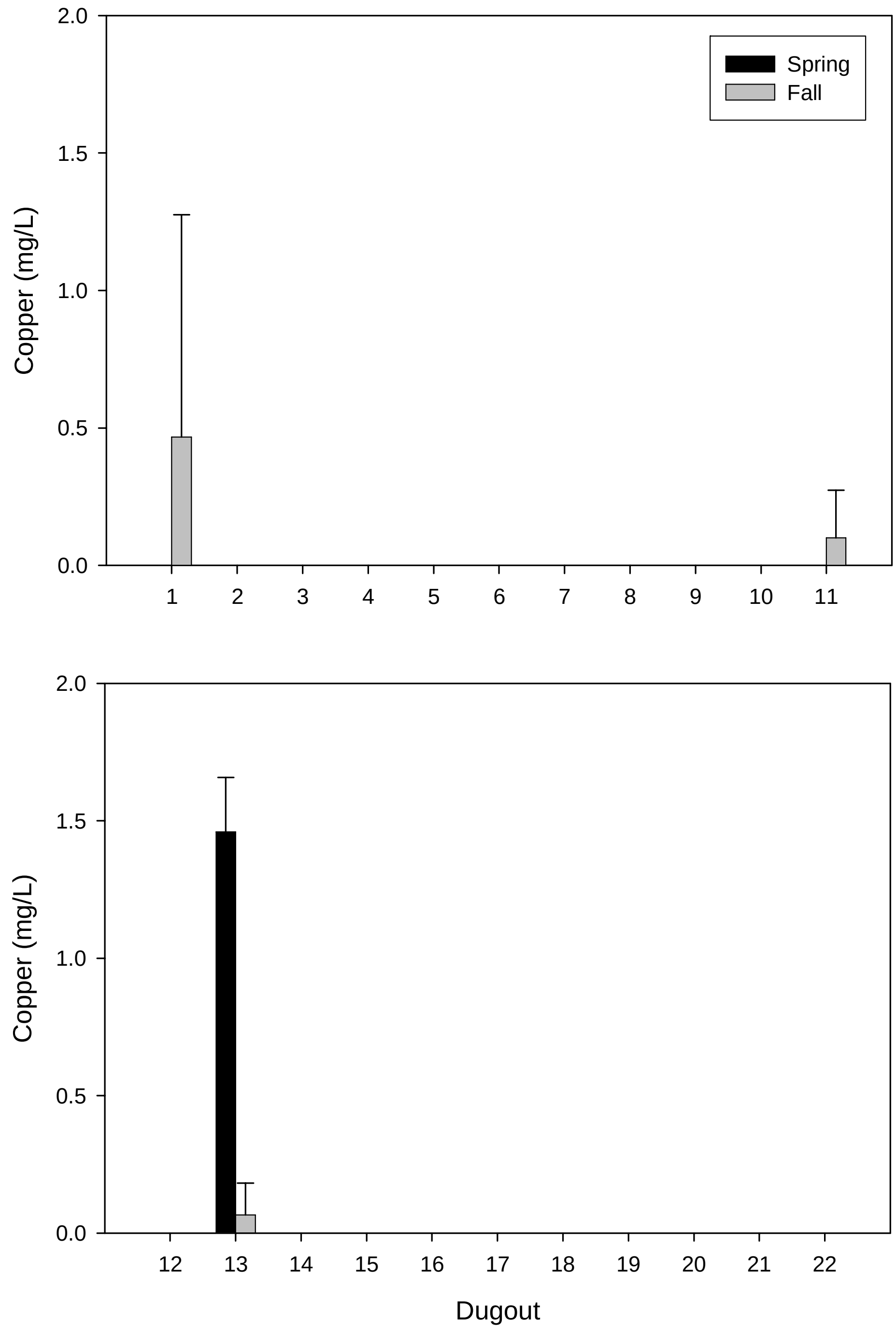

Figure C24 - Copper concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 1 mg/L. Data are presented as mean ± standard deviation.

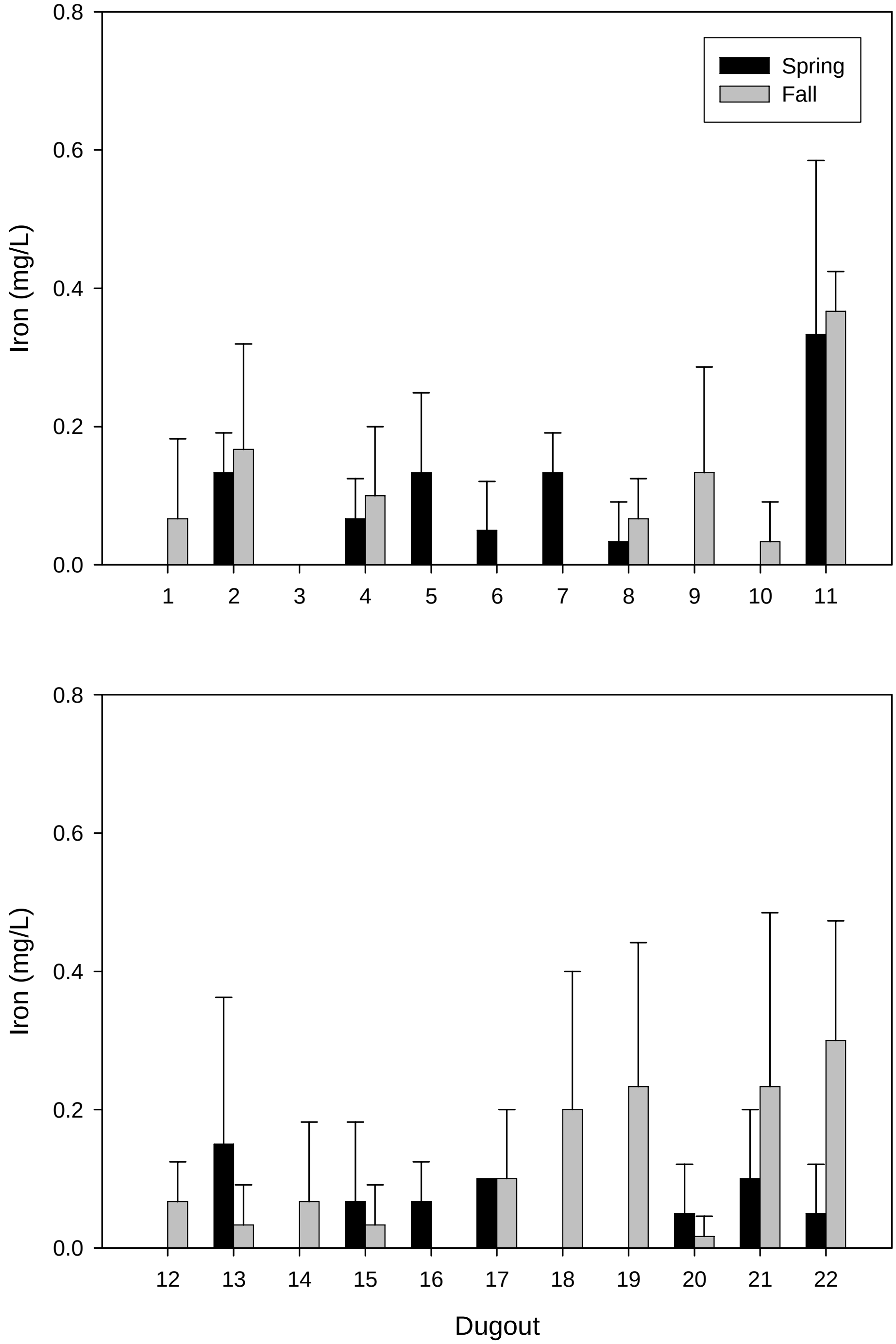

Figure C25 - Iron concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 0.3 mg/L. Data are presented as mean ± standard deviation.

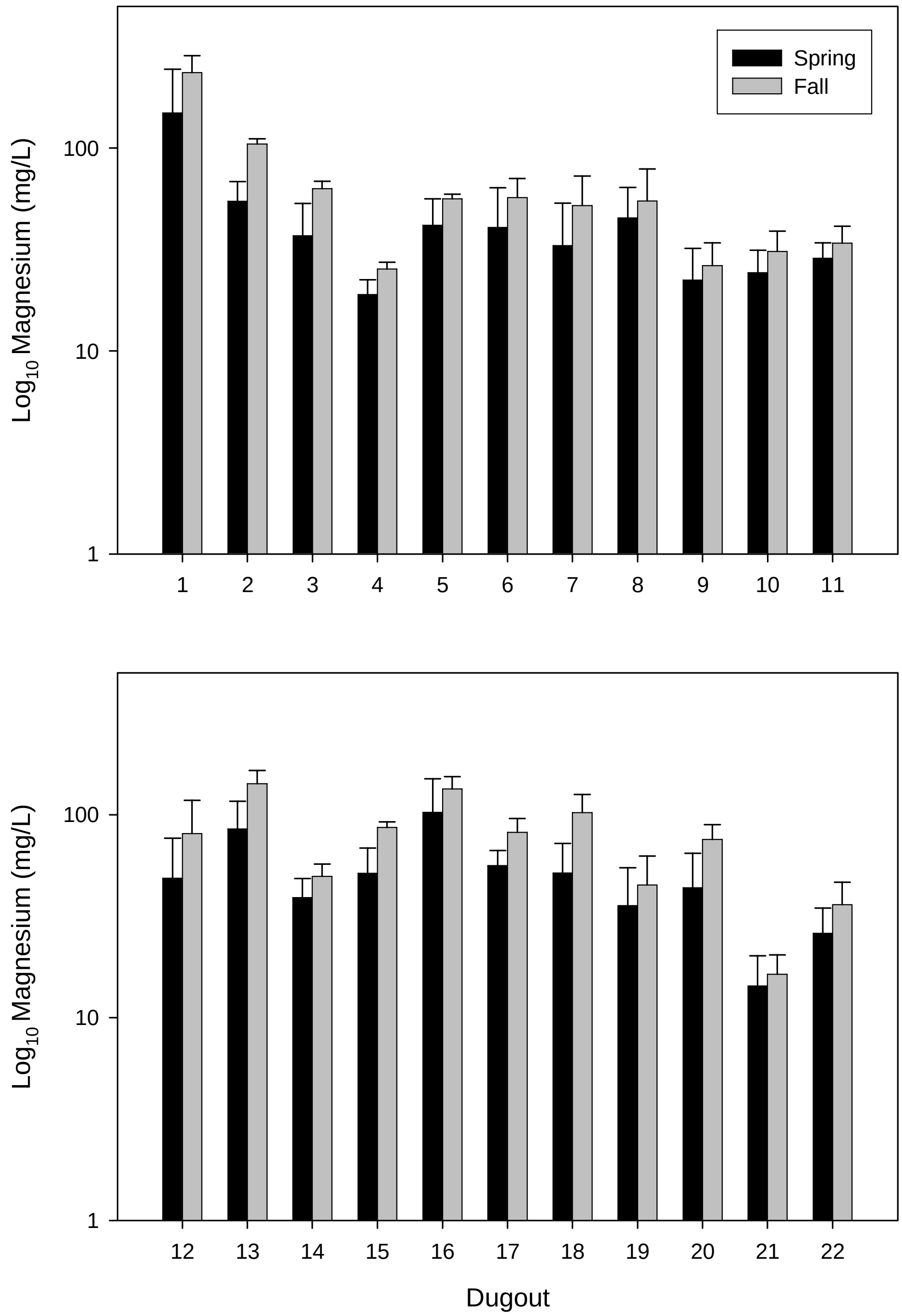

Figure C26 - Magnesium concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 200 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

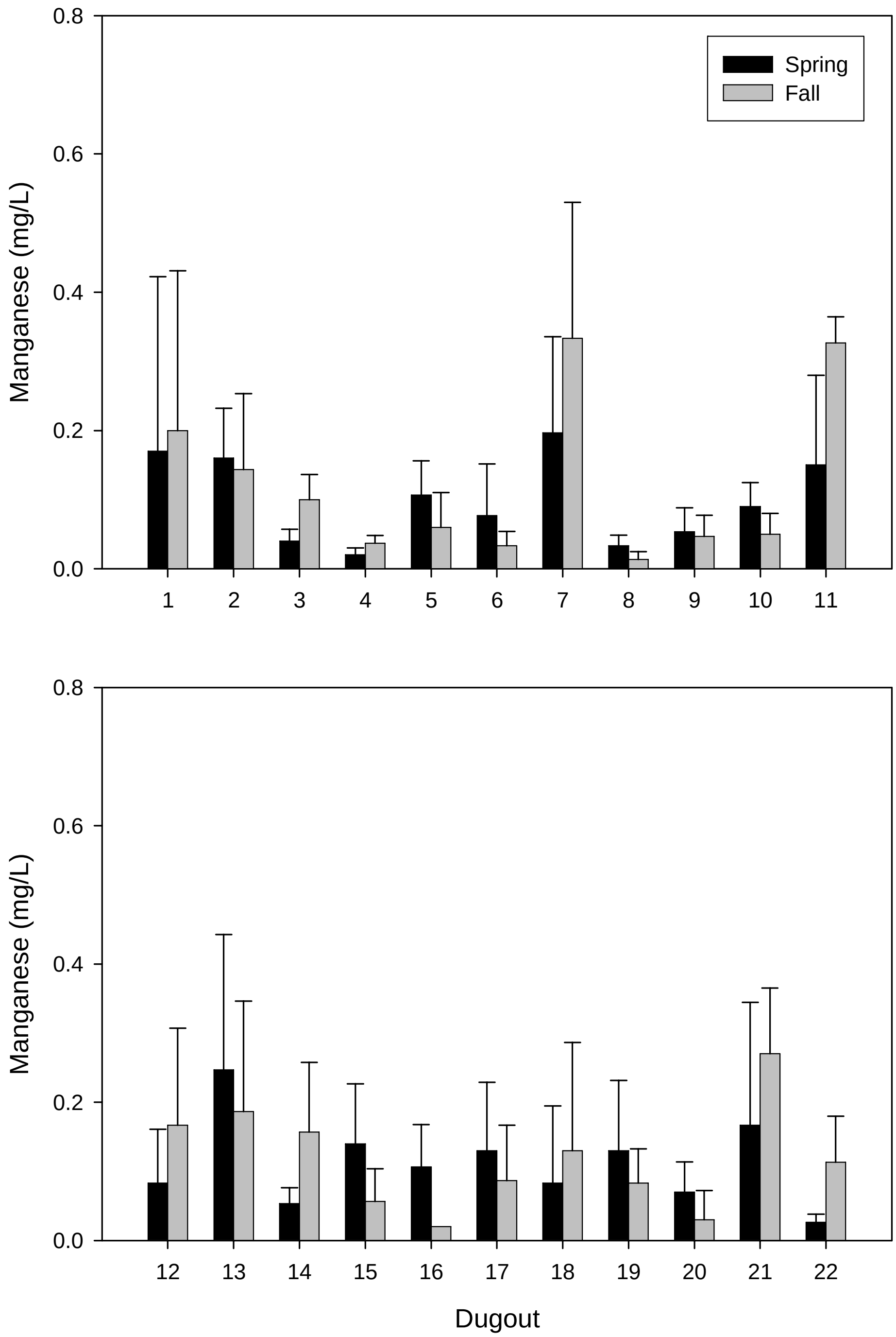

Figure C27 - Manganese concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 0.05 mg/L. Data are presented as mean ± standard deviation.

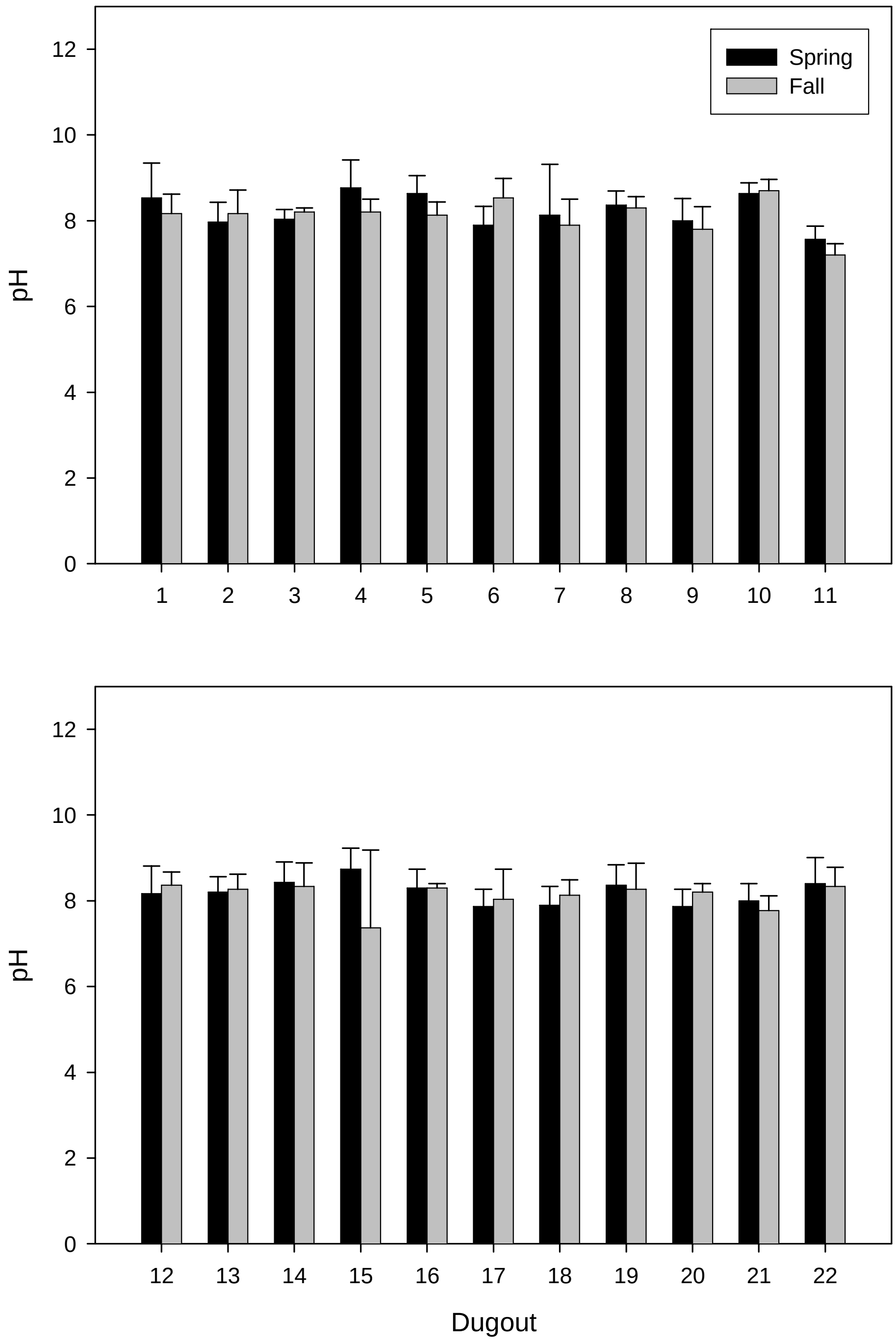

Figure C28 - The 22 dugouts with paired seasonal data pH, compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is a range from 6.5-9.0. Data are presented as mean ± standard deviation.

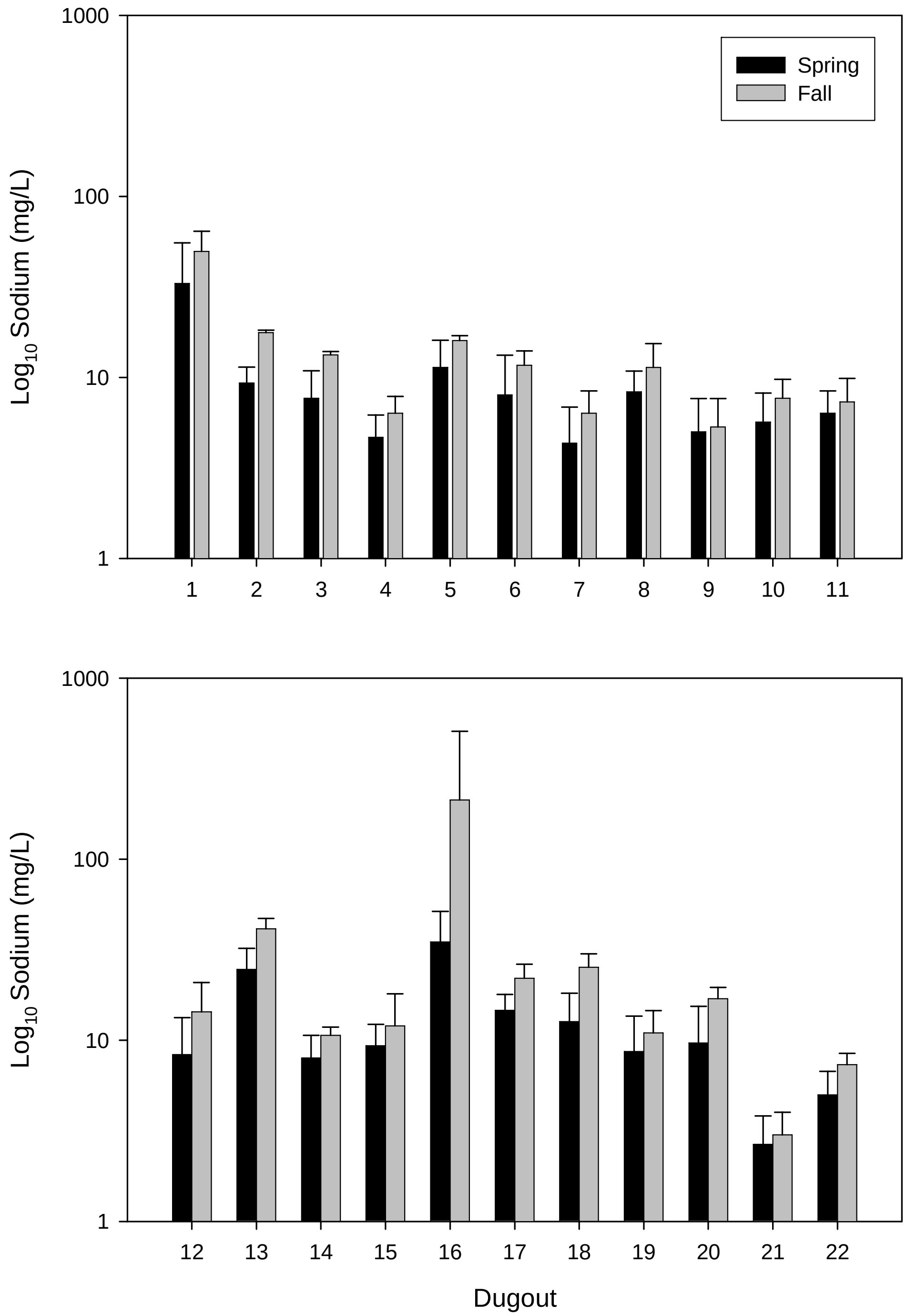

Figure C29 - Sodium concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 300 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

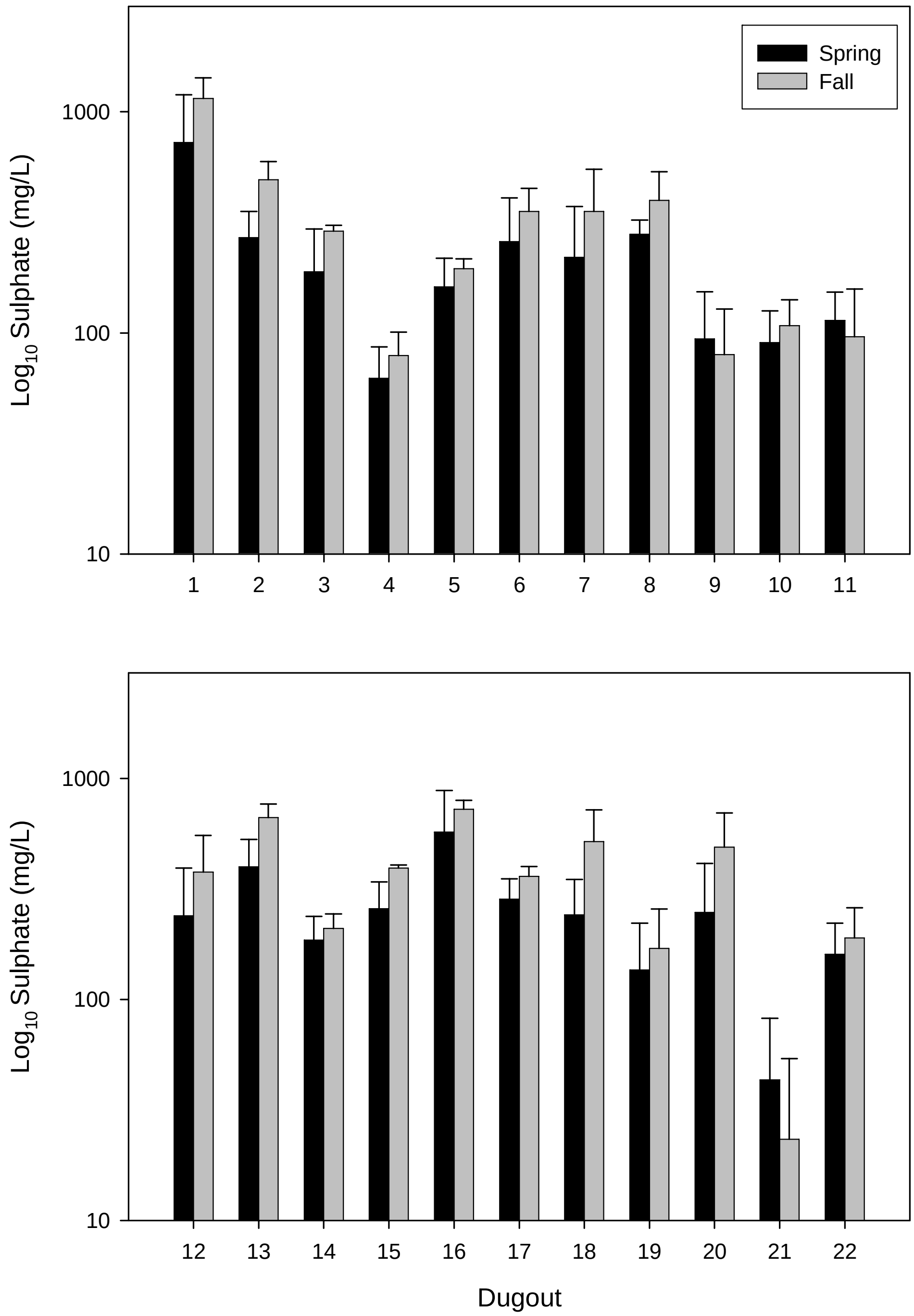

Figure C30 - Sulphate concentration of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is 500 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

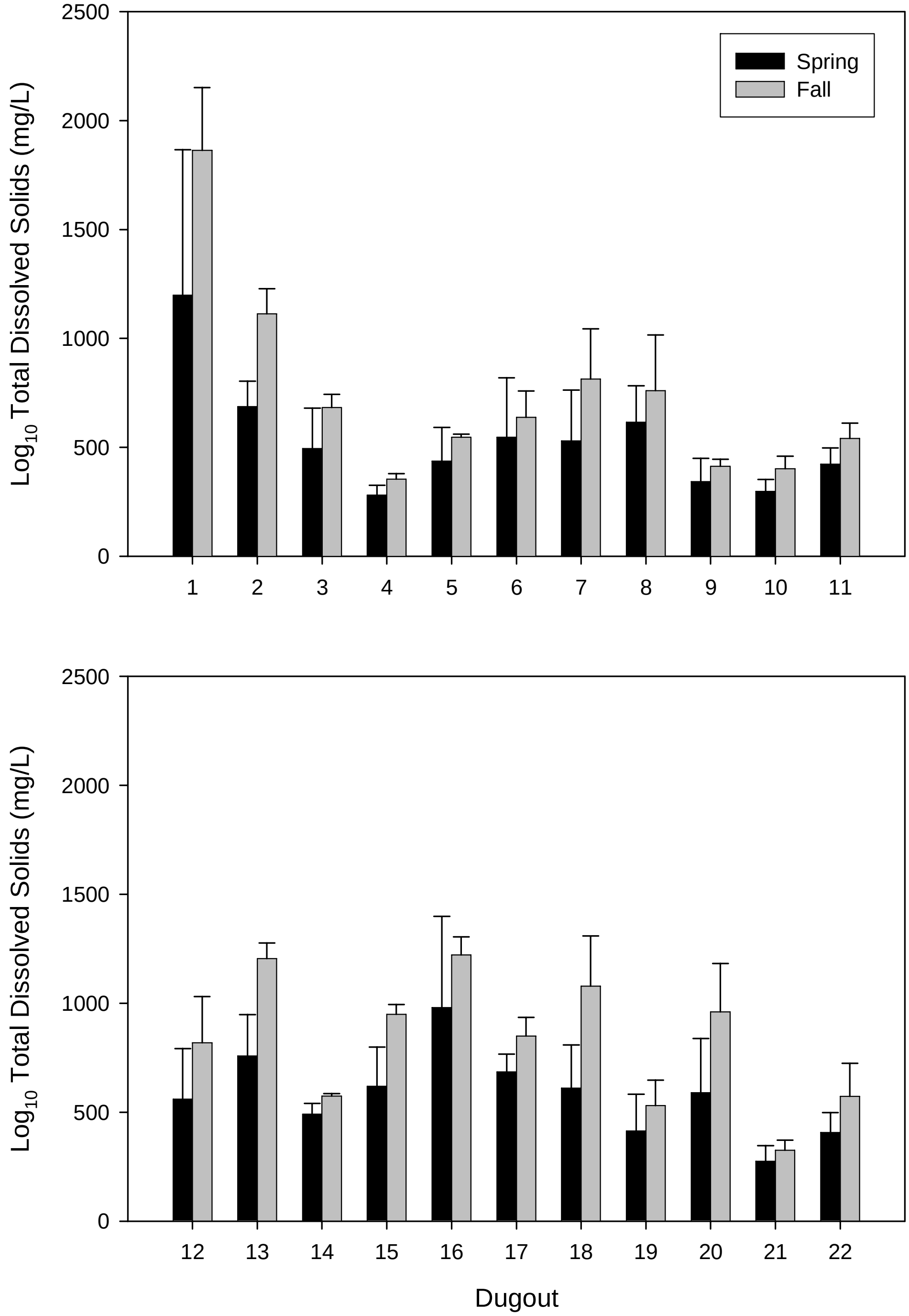

Figure C31 - Total Dissolved Solids of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is less than 1,500 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

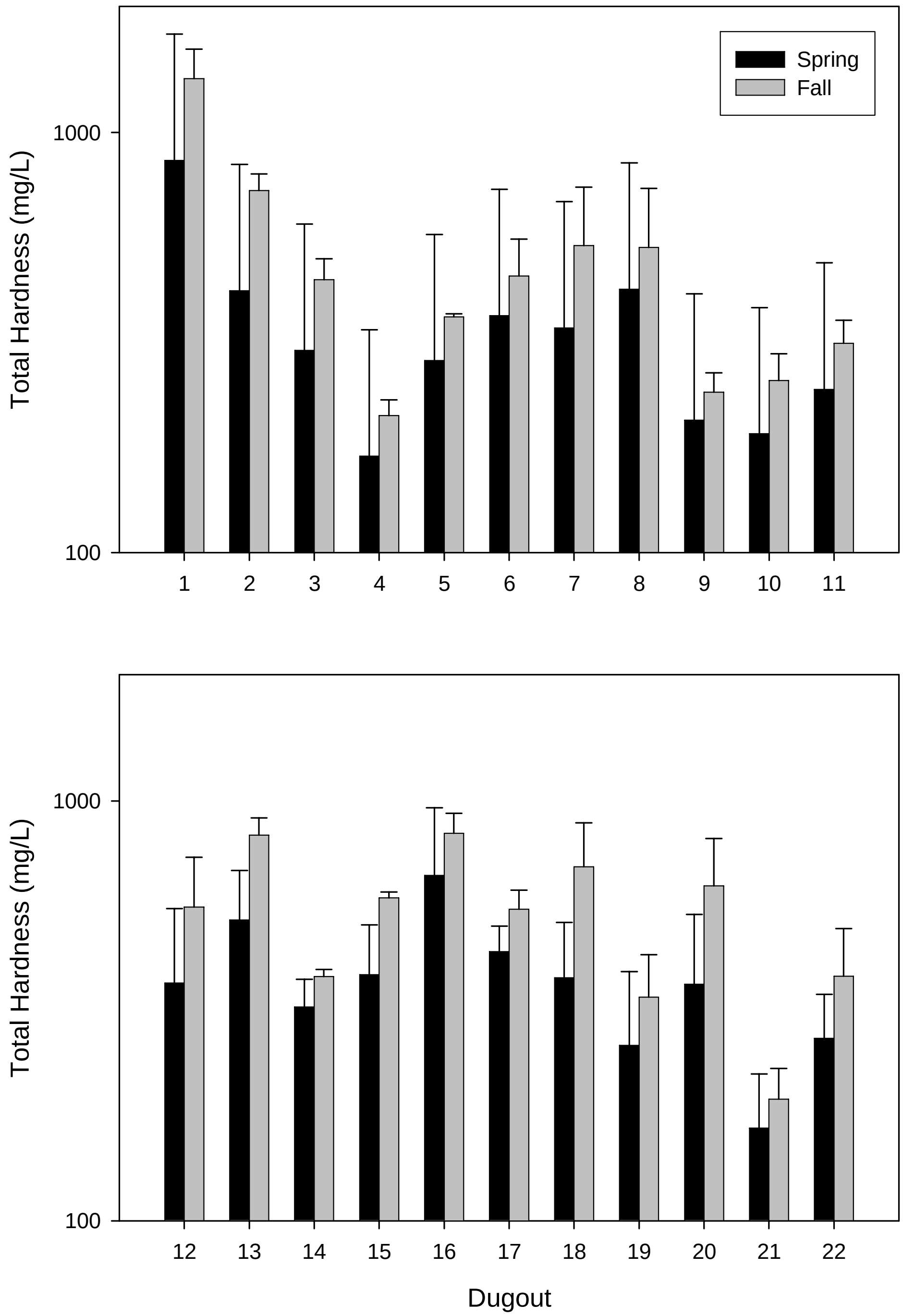

Figure C32 - Total Hardness of the 22 dugouts with paired seasonal data compared by the season that the sample was taken. The *Municipal Drinking Water Aesthetic Objective* is less than 800 mg/L. Data are presented as mean ± standard deviation. Note: log scale.

Appendix D

Box Plots Summarizing Water Quality Parameter Concentration

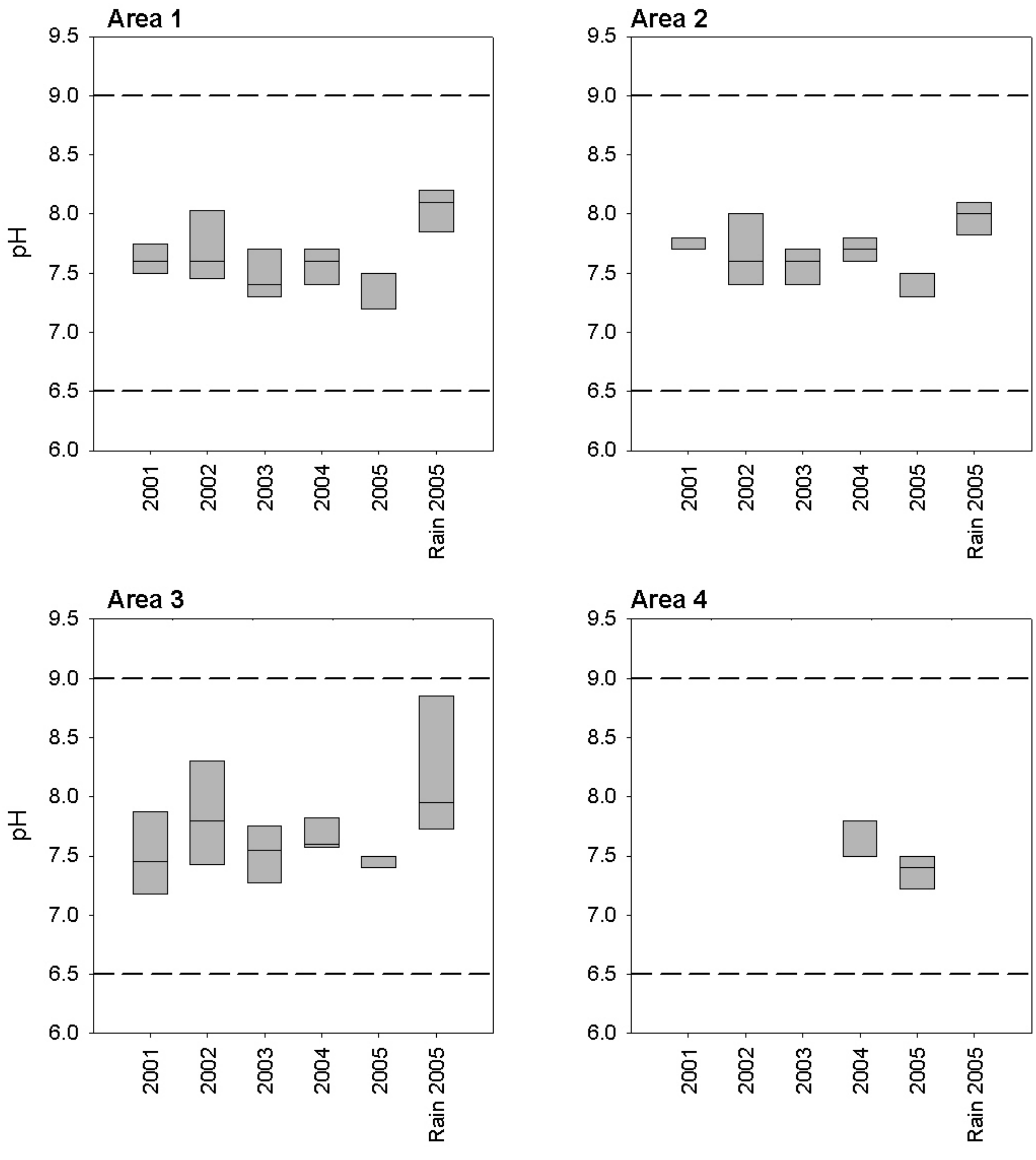

Figure D1. Box plots summarizing pH values for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent Saskatchewan surface water quality objectives (greater than pH 6.5, less than pH 9.0).

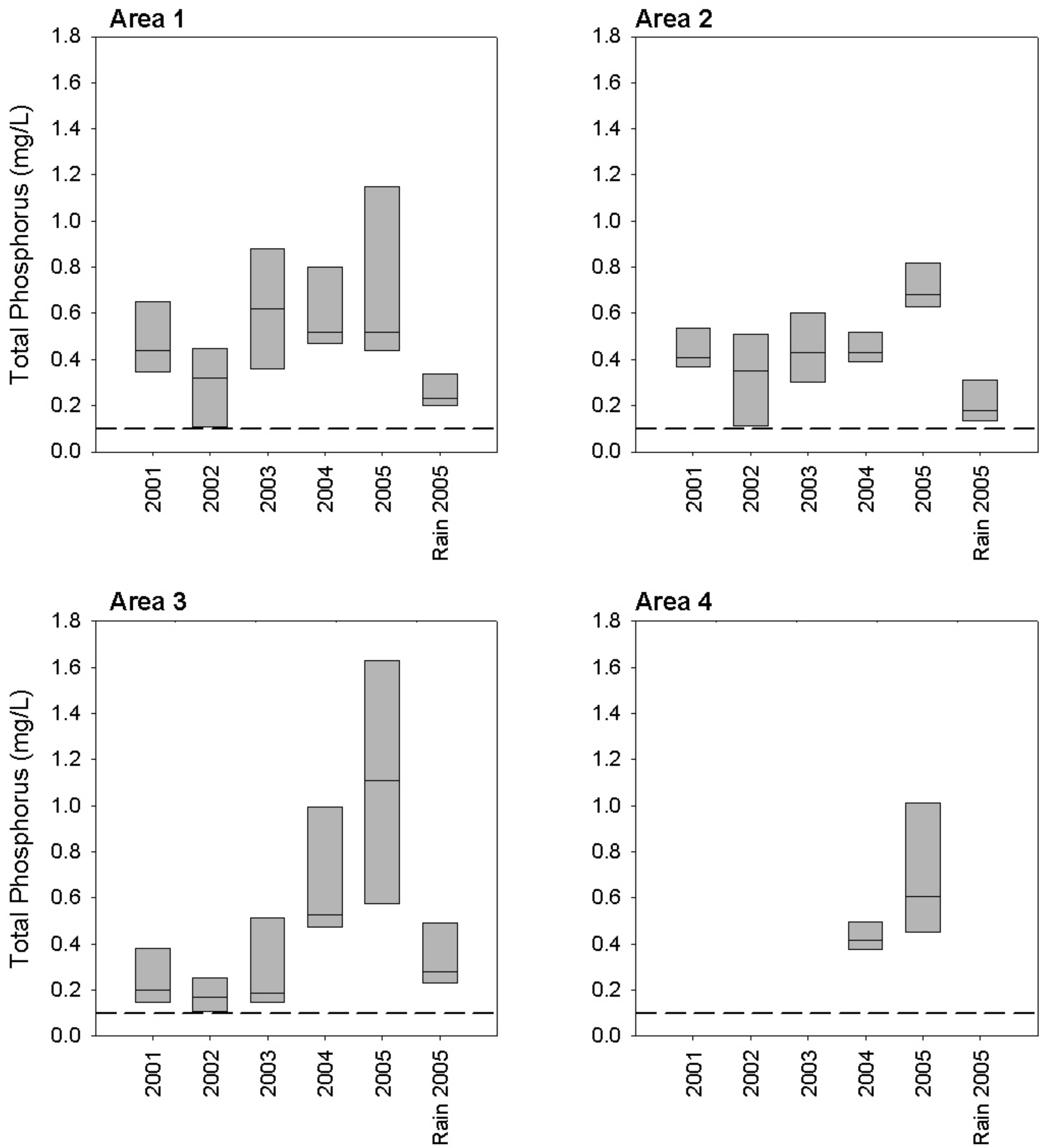

Figure D2. Box plots summarizing total phosphorus concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent the surface water quality objectives that Saskatchewan Watershed Authority uses in its assessment of surface water quality.

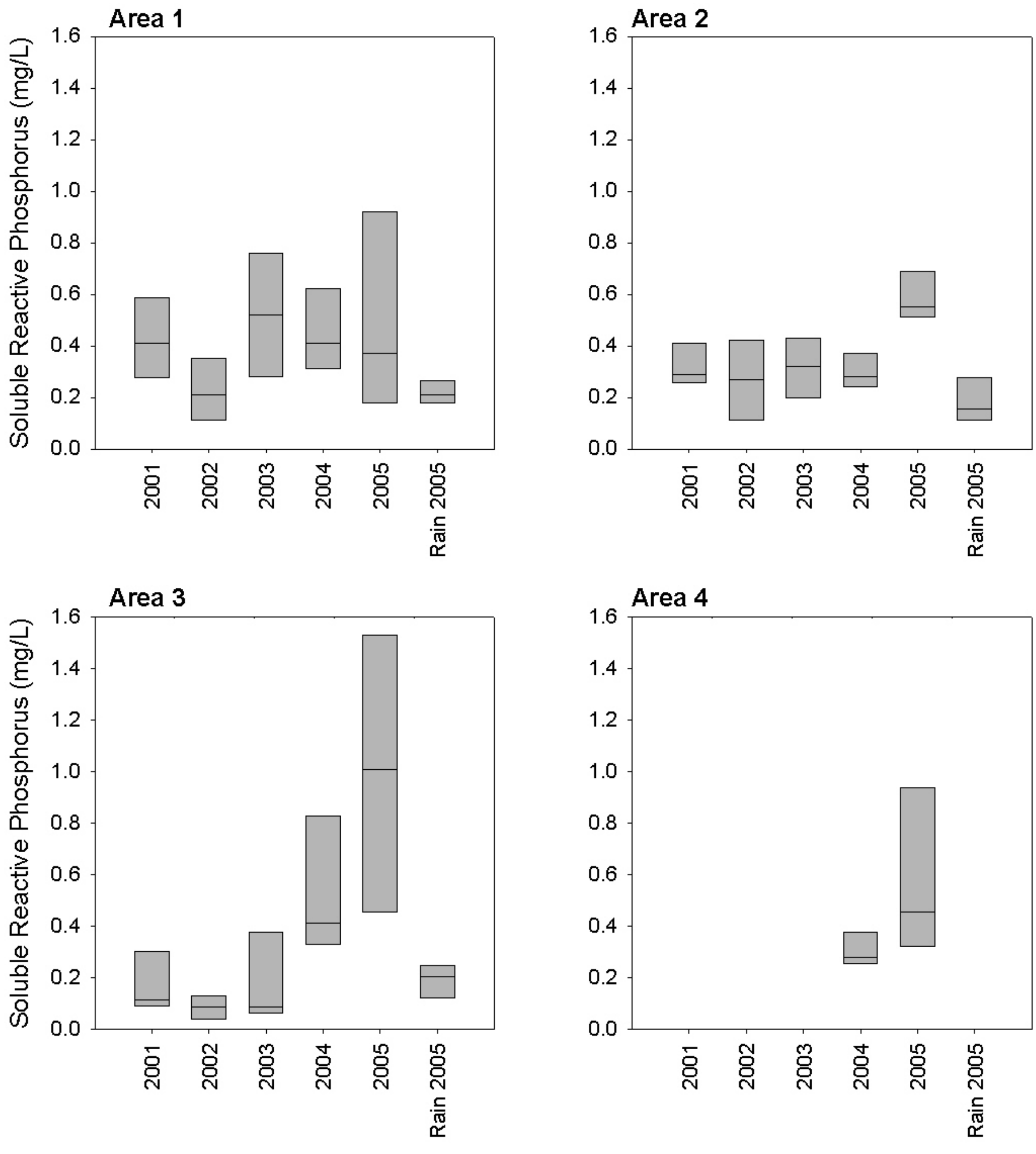

Figure D3. Box plots summarizing soluble reactive phosphorus (ortho-phosphate) concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

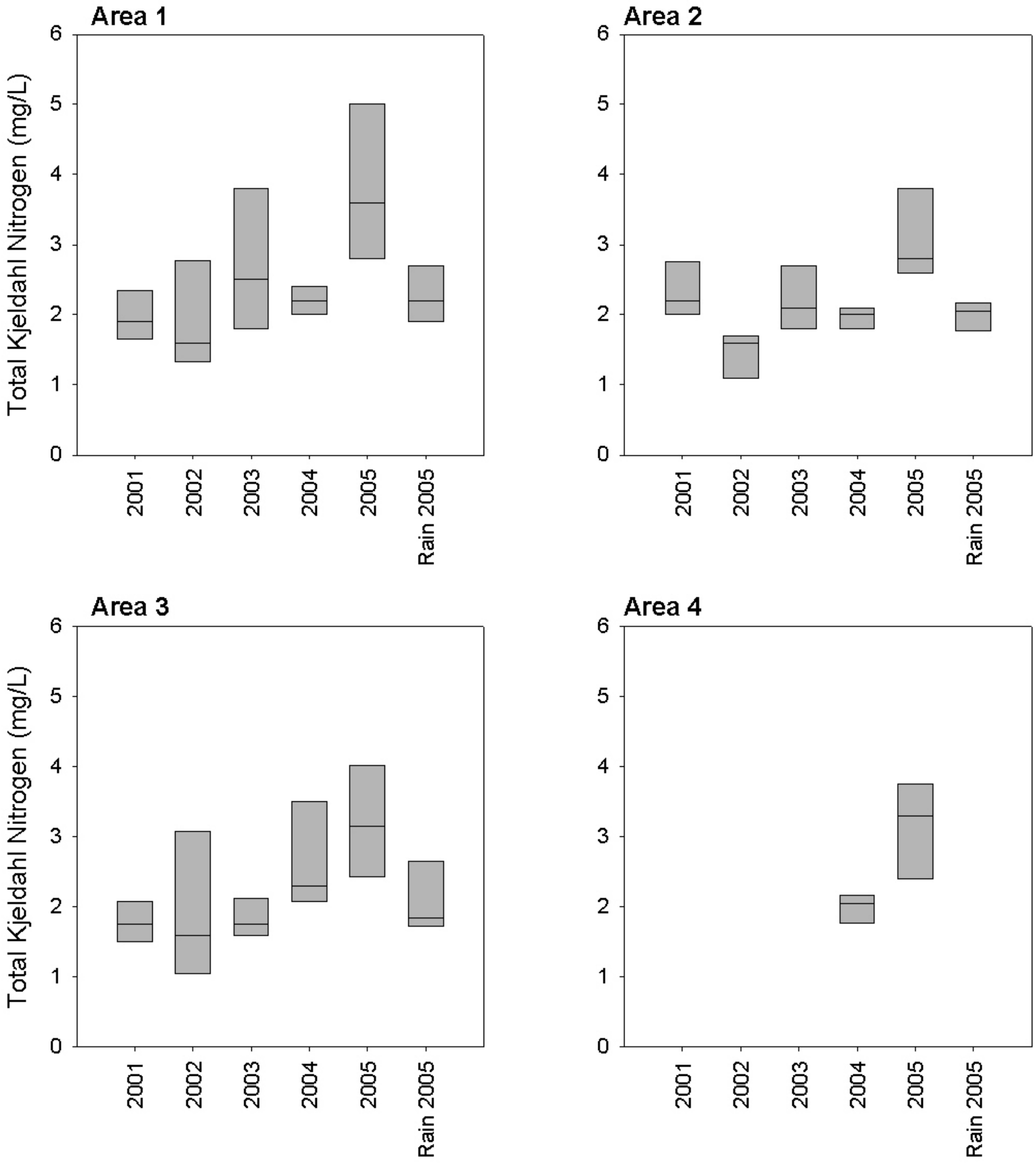

Figure D4. Box plots summarizing total Kjeldahl nitrogen concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

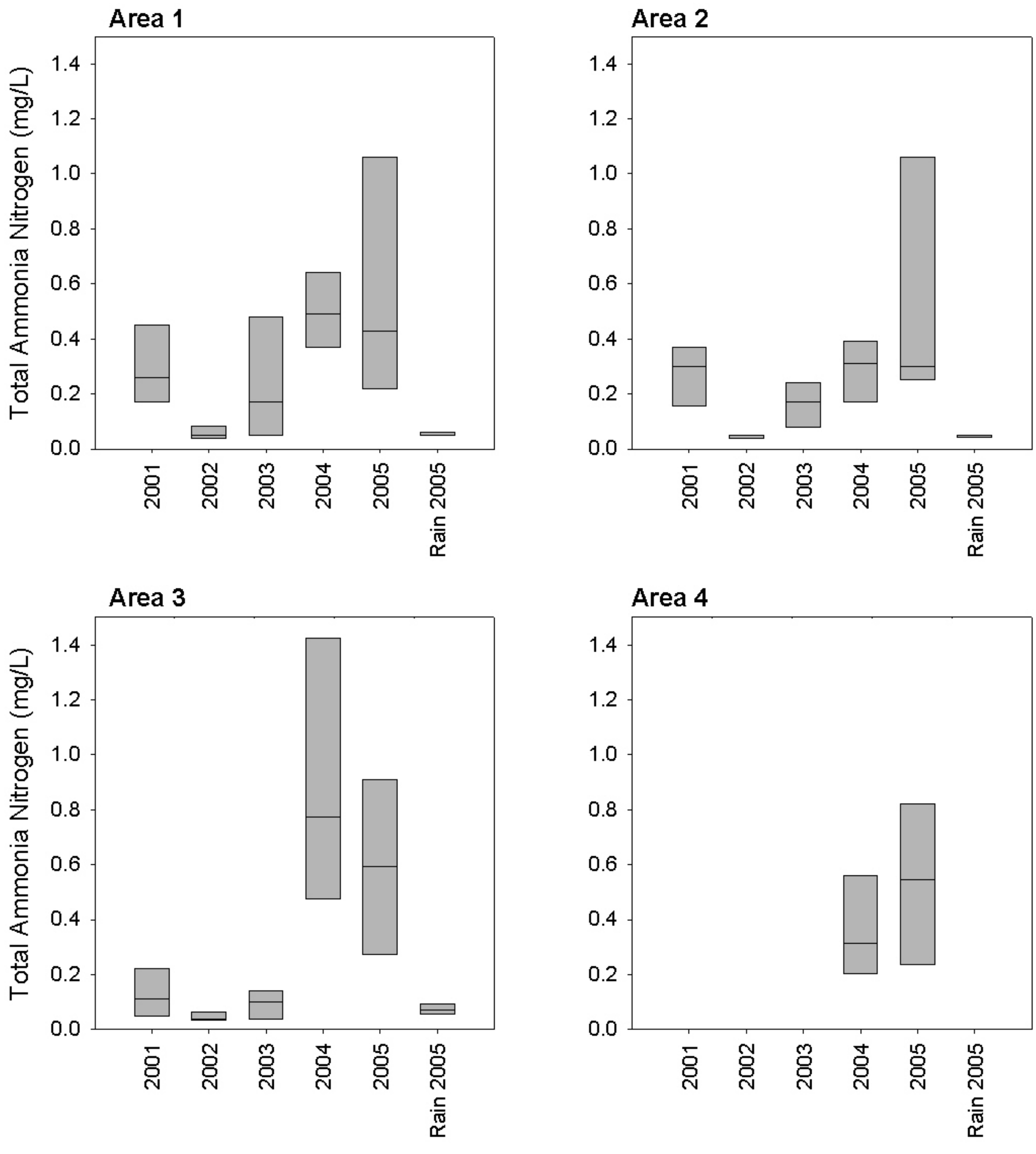

Figure D5. Box plots summarizing total ammonia nitrogen (as N) concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

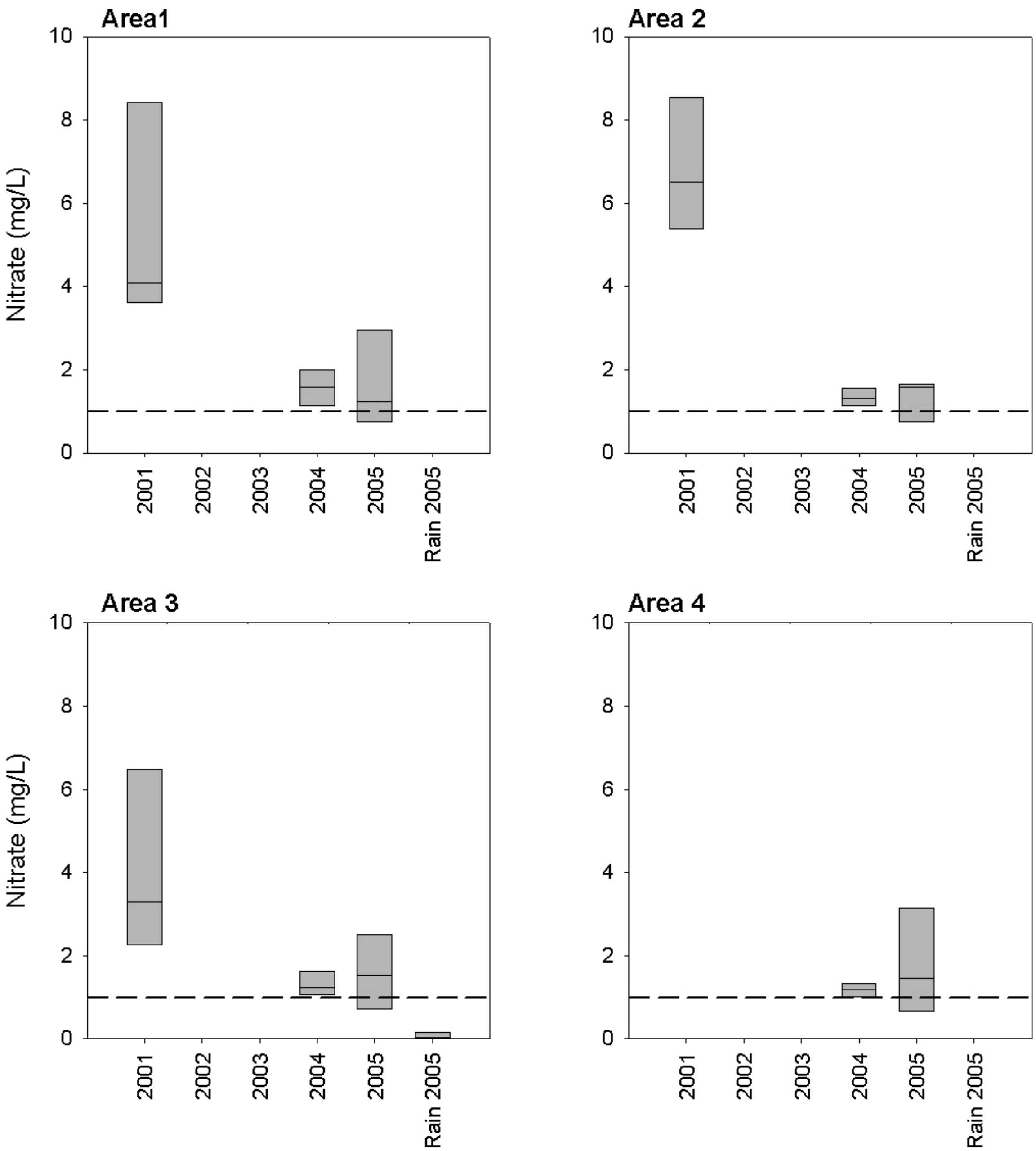

Figure D6. Box plots summarizing nitrate (as N) concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent the surface water quality objectives that Saskatchewan Watershed Authority uses in its assessment of surface water quality

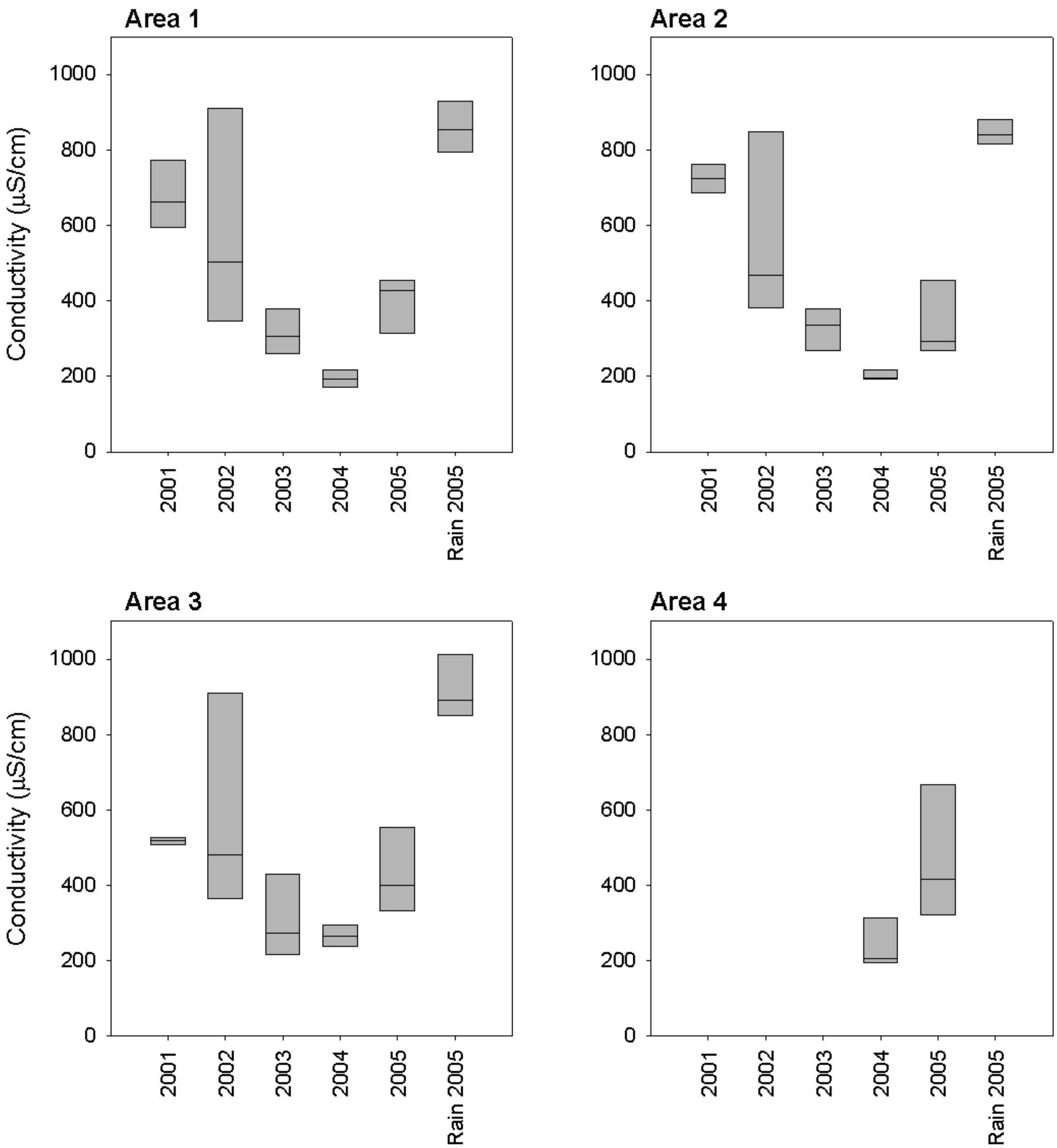

Figure D7. Box plots summarizing conductivity values for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

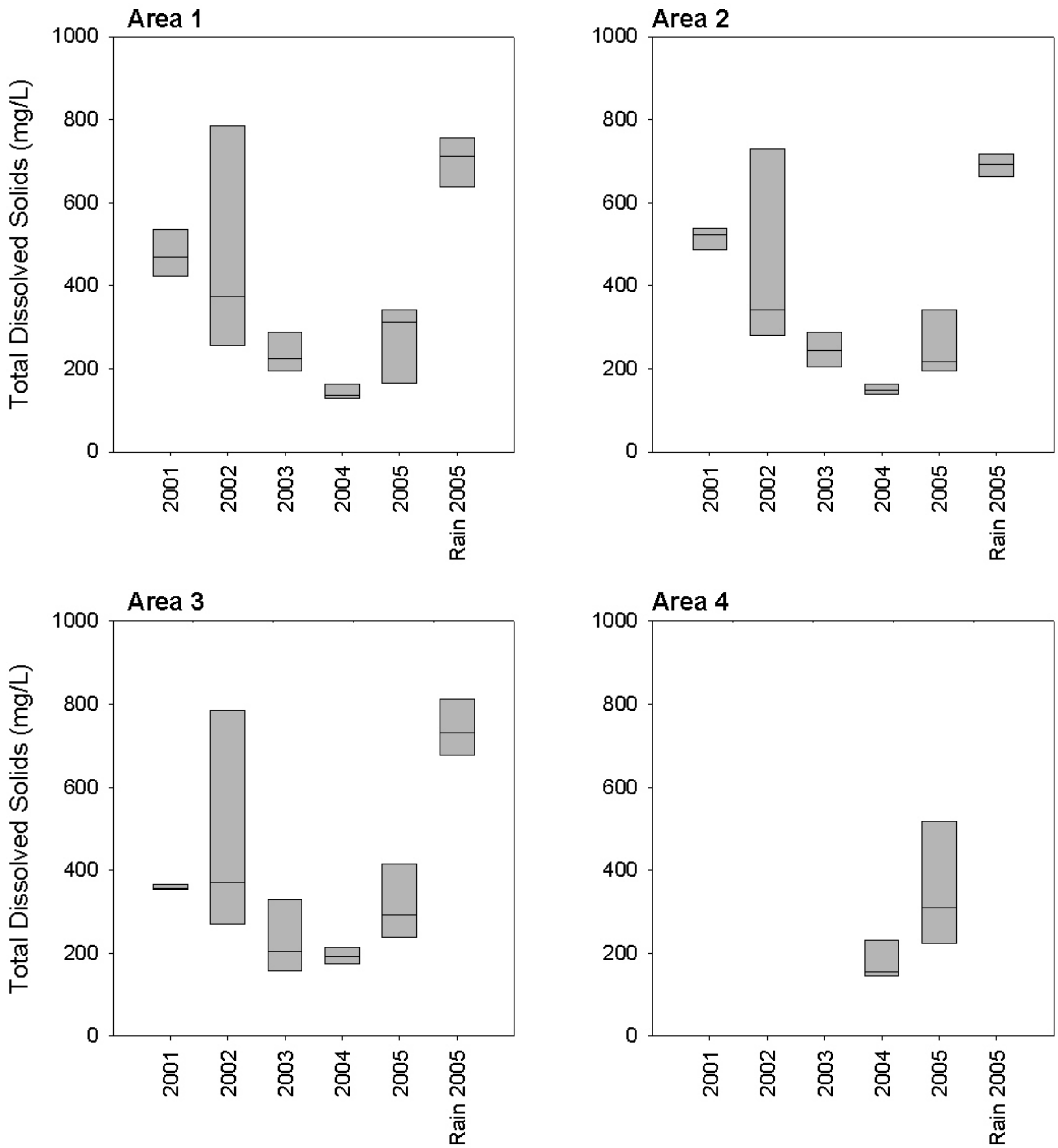

Figure D8. Box plots summarizing total dissolved solid concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

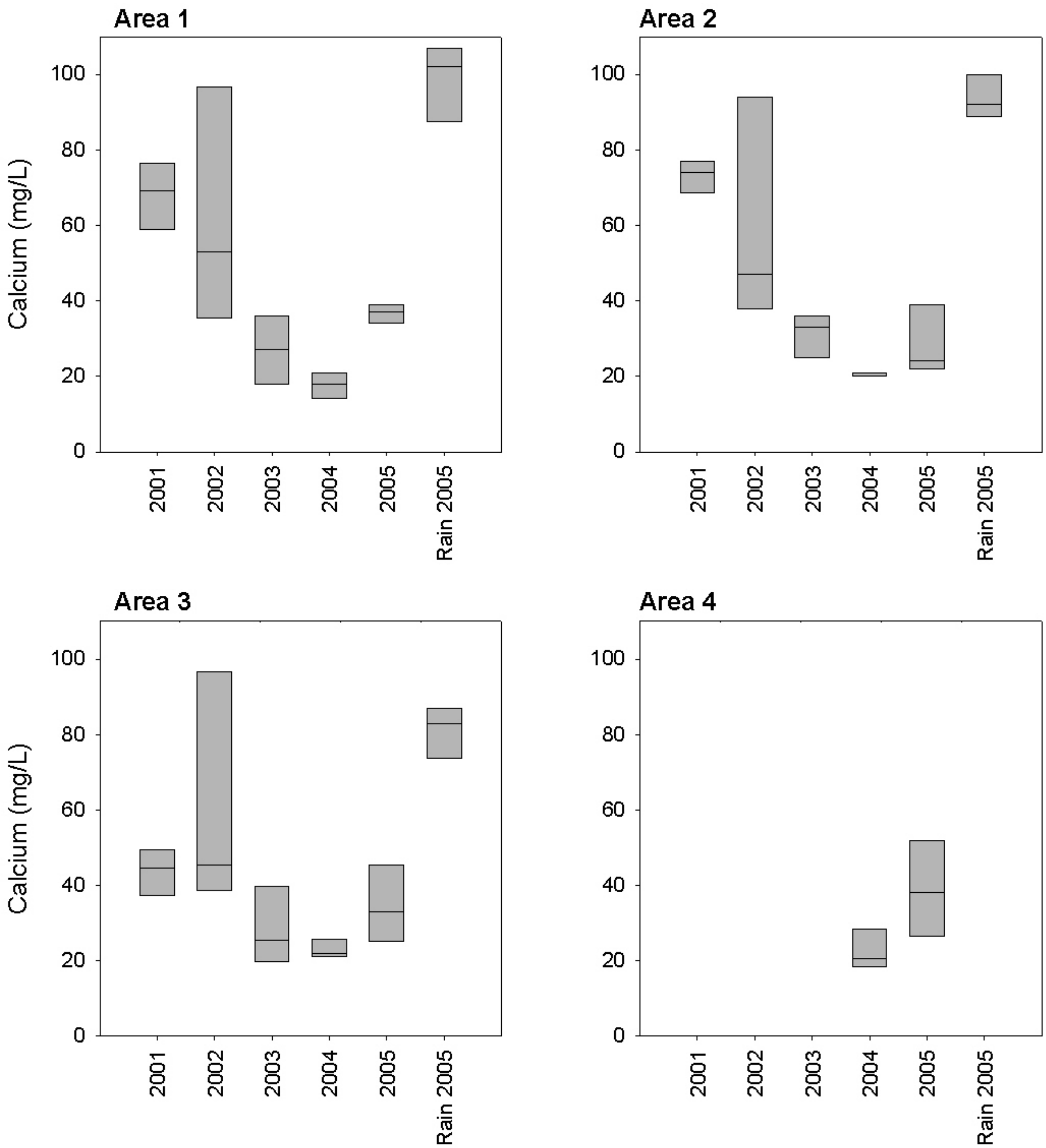

Figure D9. Box plots summarizing calcium concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

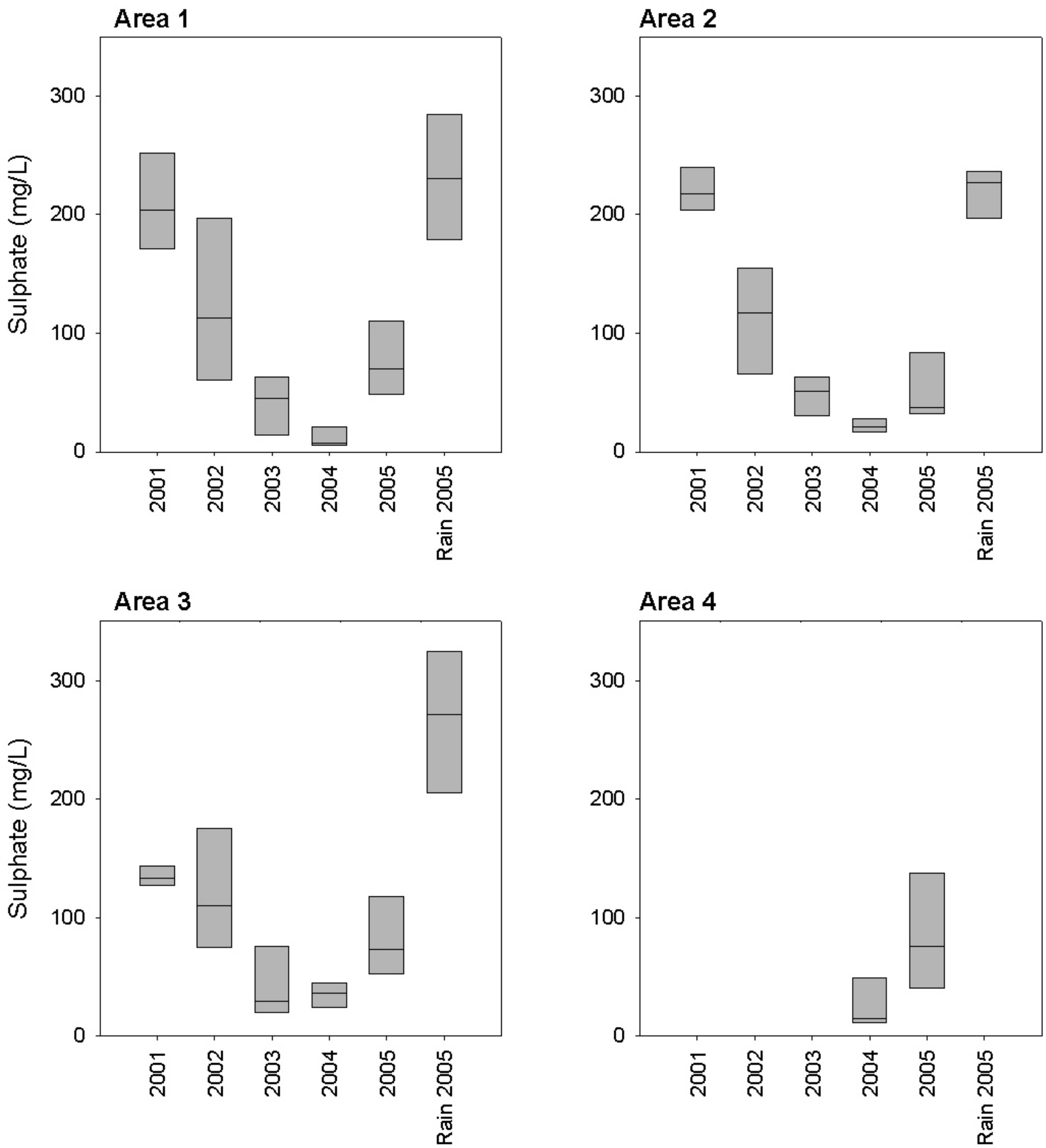

Figure D10. Box plots summarizing sulphate concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

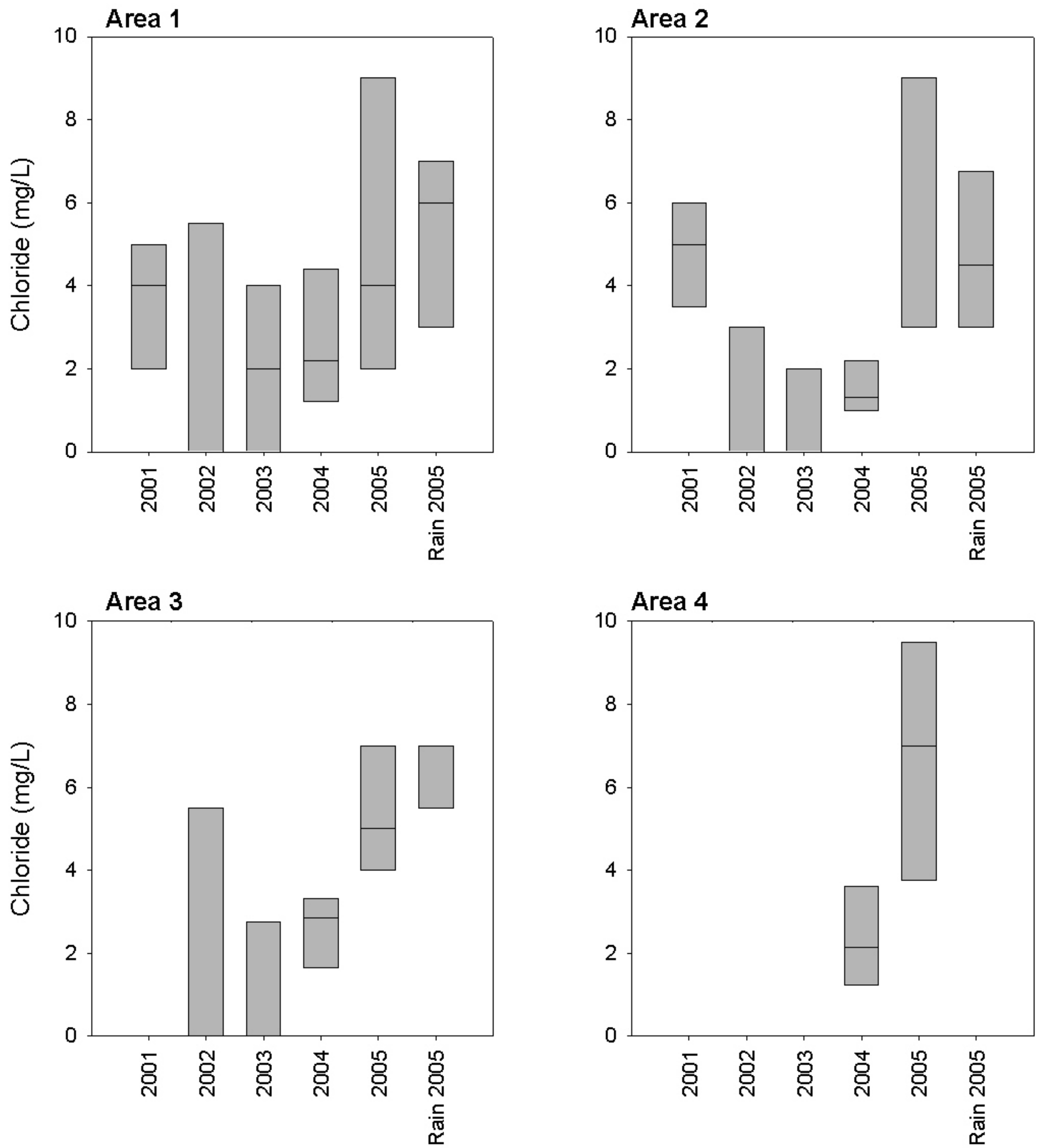

Figure D11. Box plots summarizing chloride concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

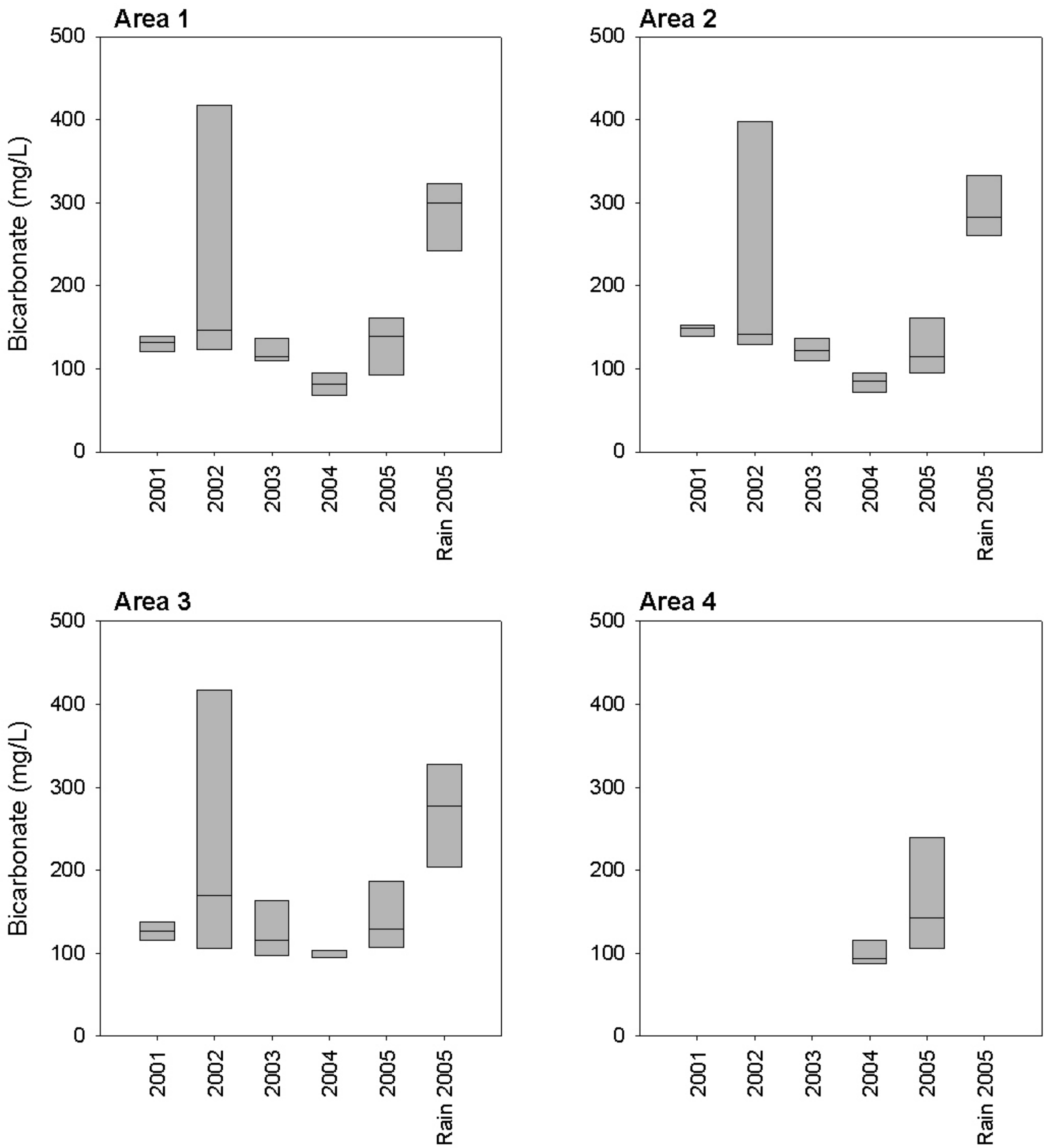

Figure D12. Box plots summarizing bicarbonate concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

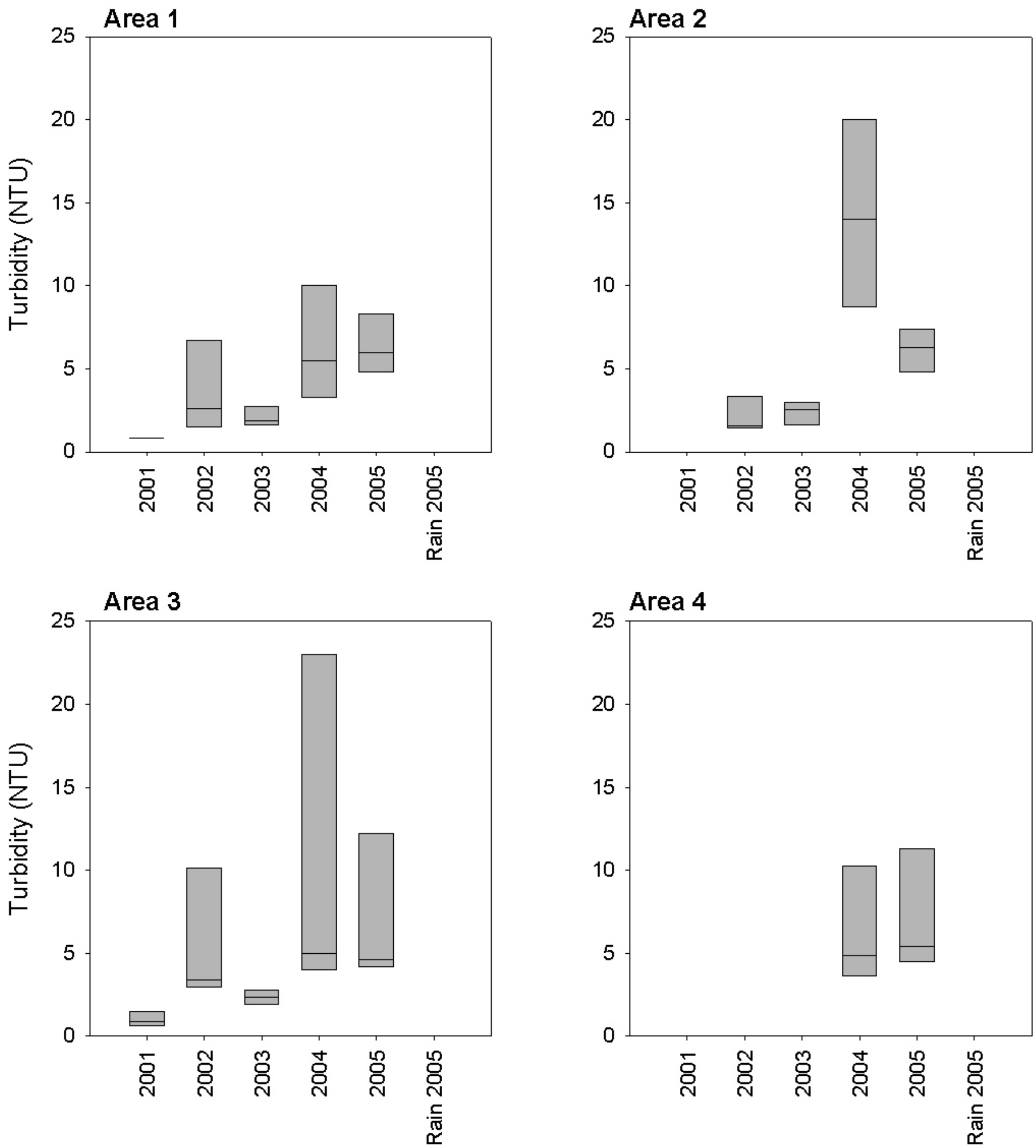

Figure D13. Box plots summarizing tubidity values for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

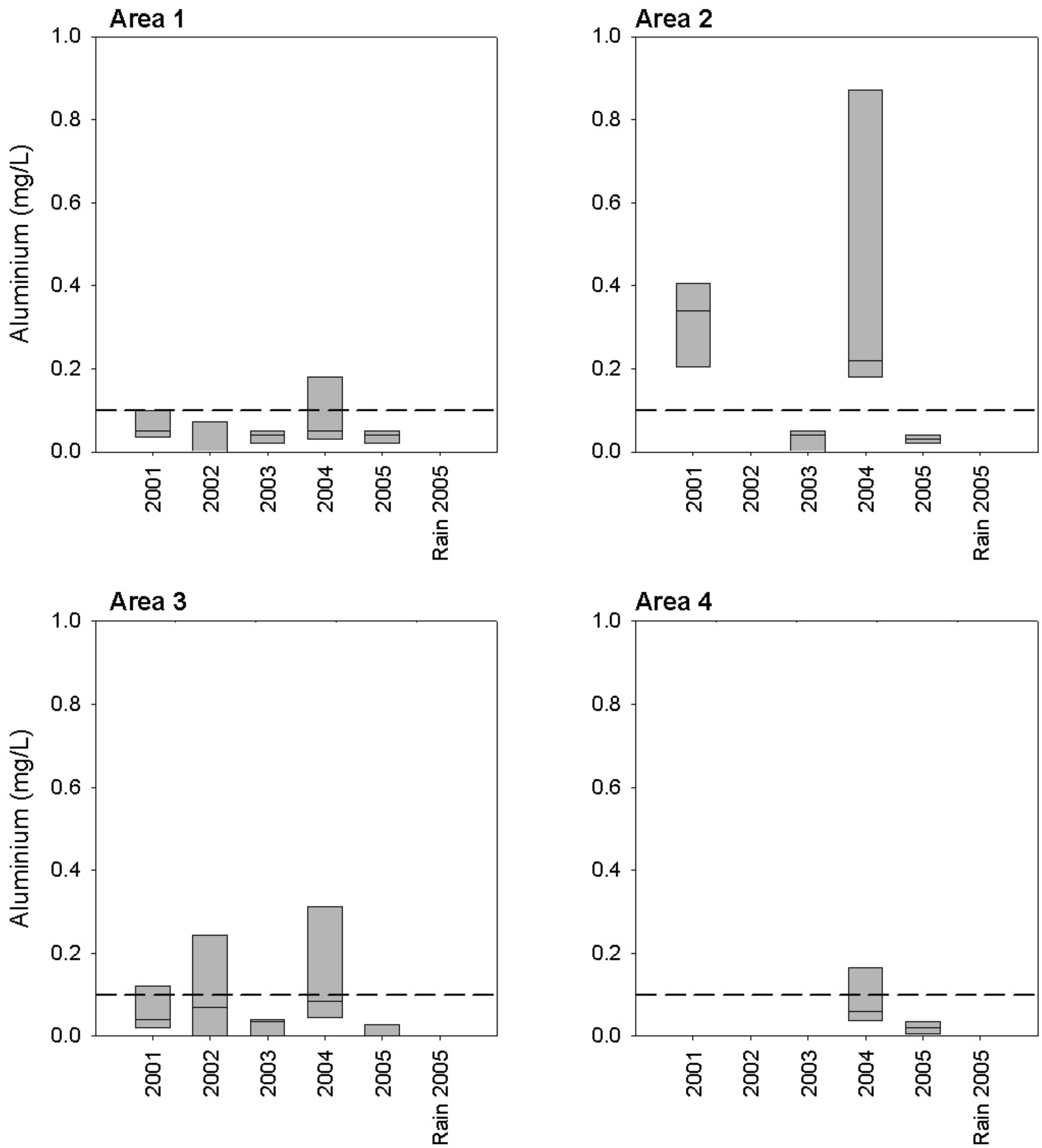

Figure D14. Box plots summarizing aluminium concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent the surface water quality objective.

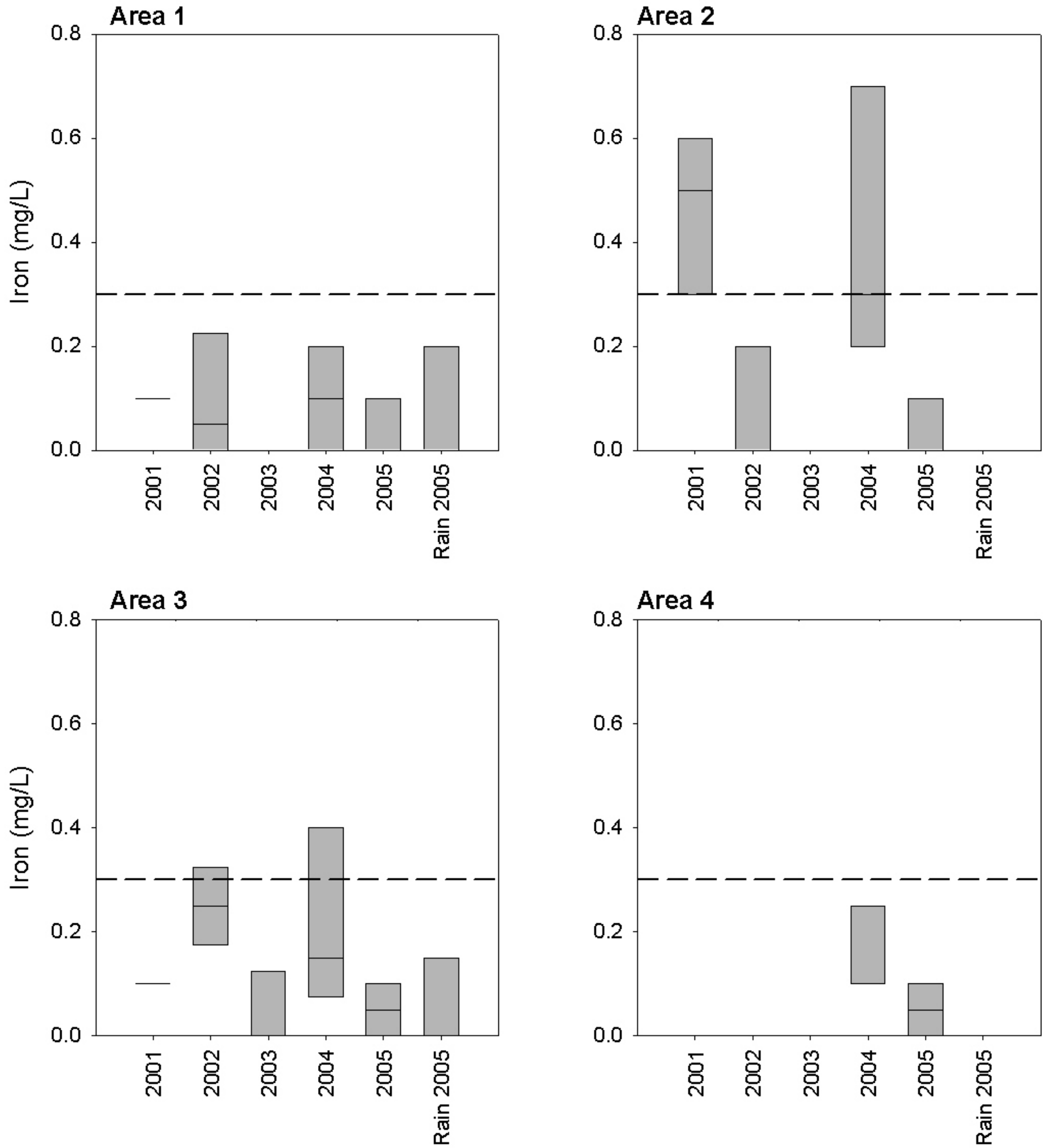

Figure D15. Box plots summarizing iron concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent the surface water quality objective.

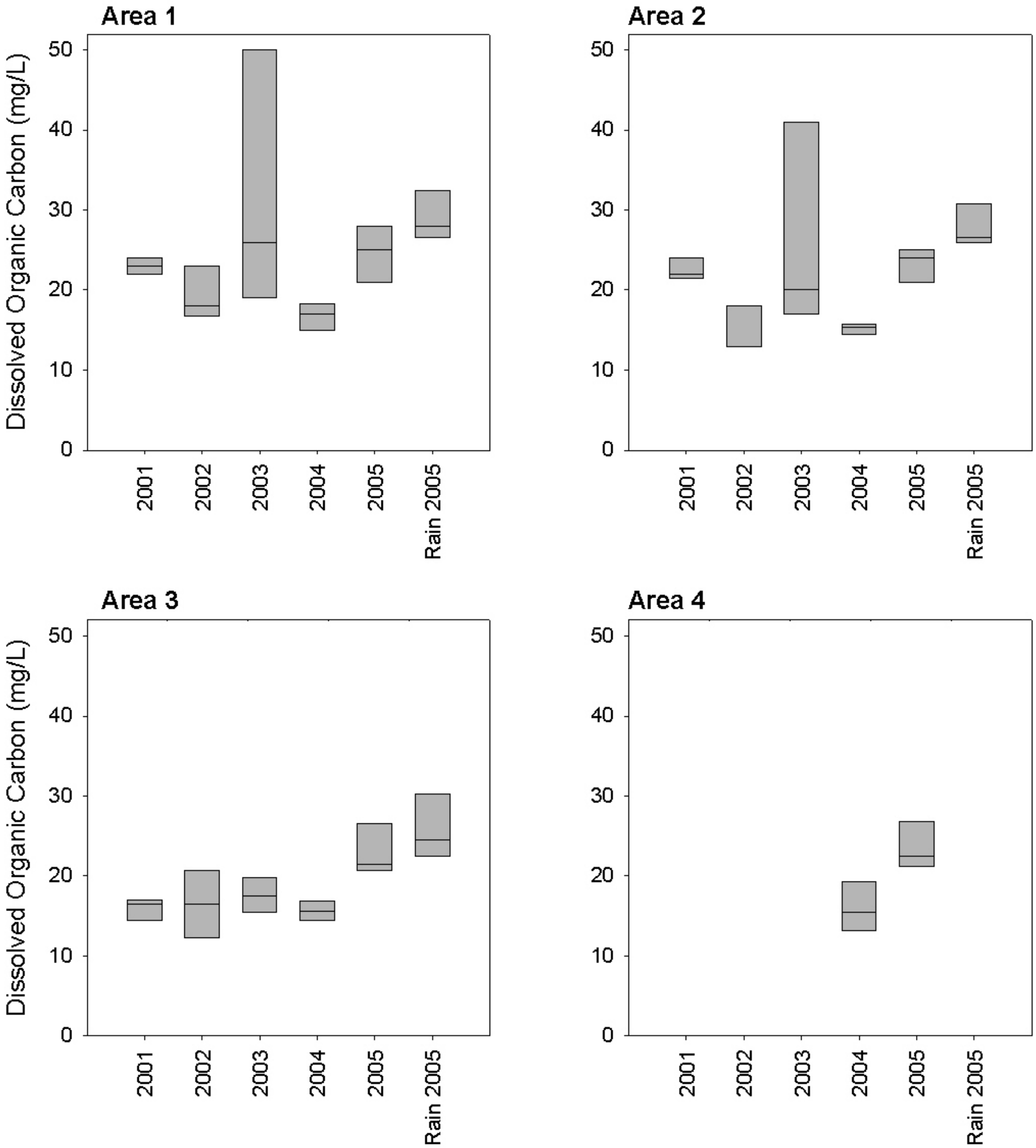

Figure D16. Box plots summarizing dissolved organic carbon concentrations for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

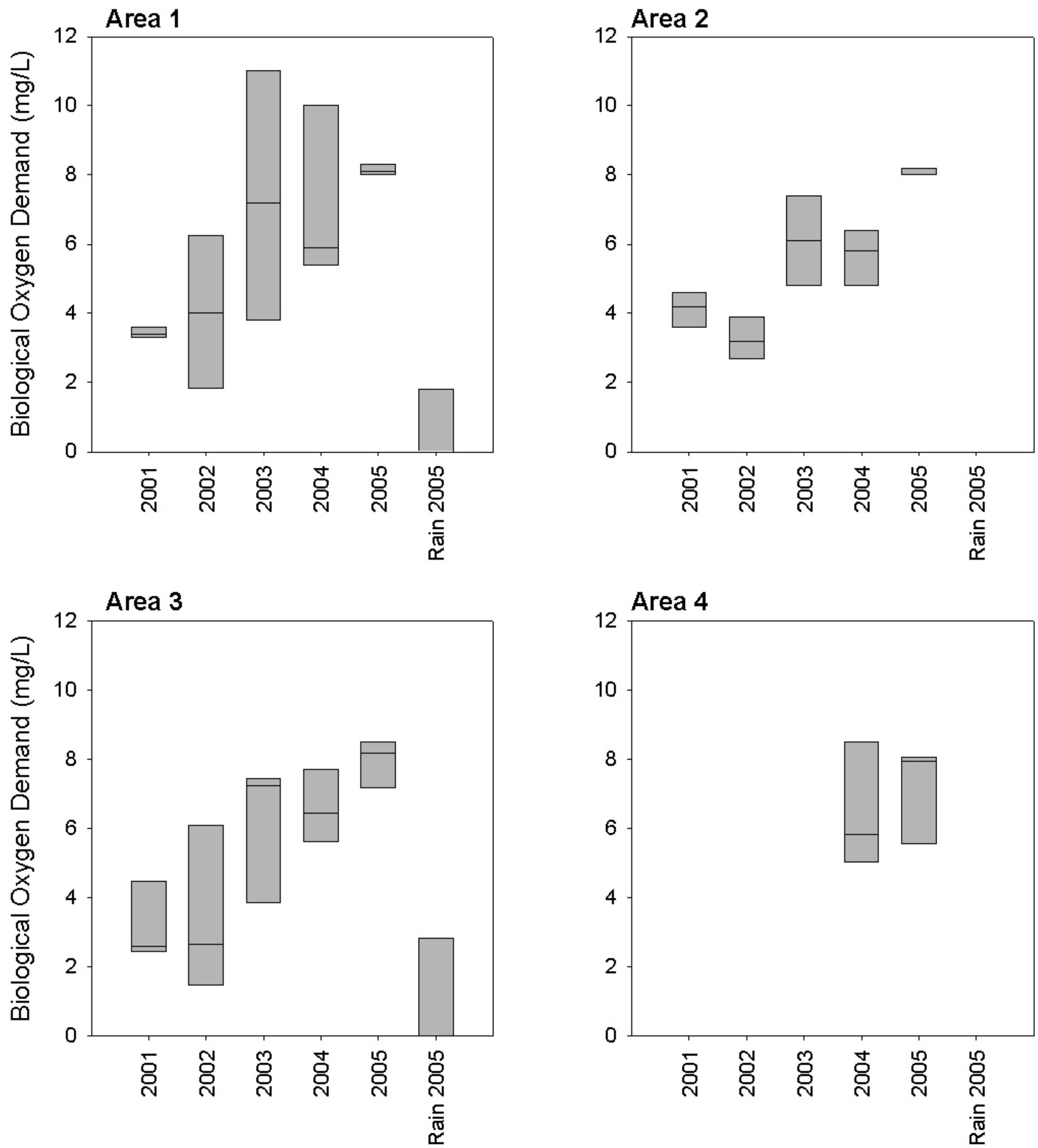

Figure D17. Box plots summarizing biological oxygen demand values for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations.

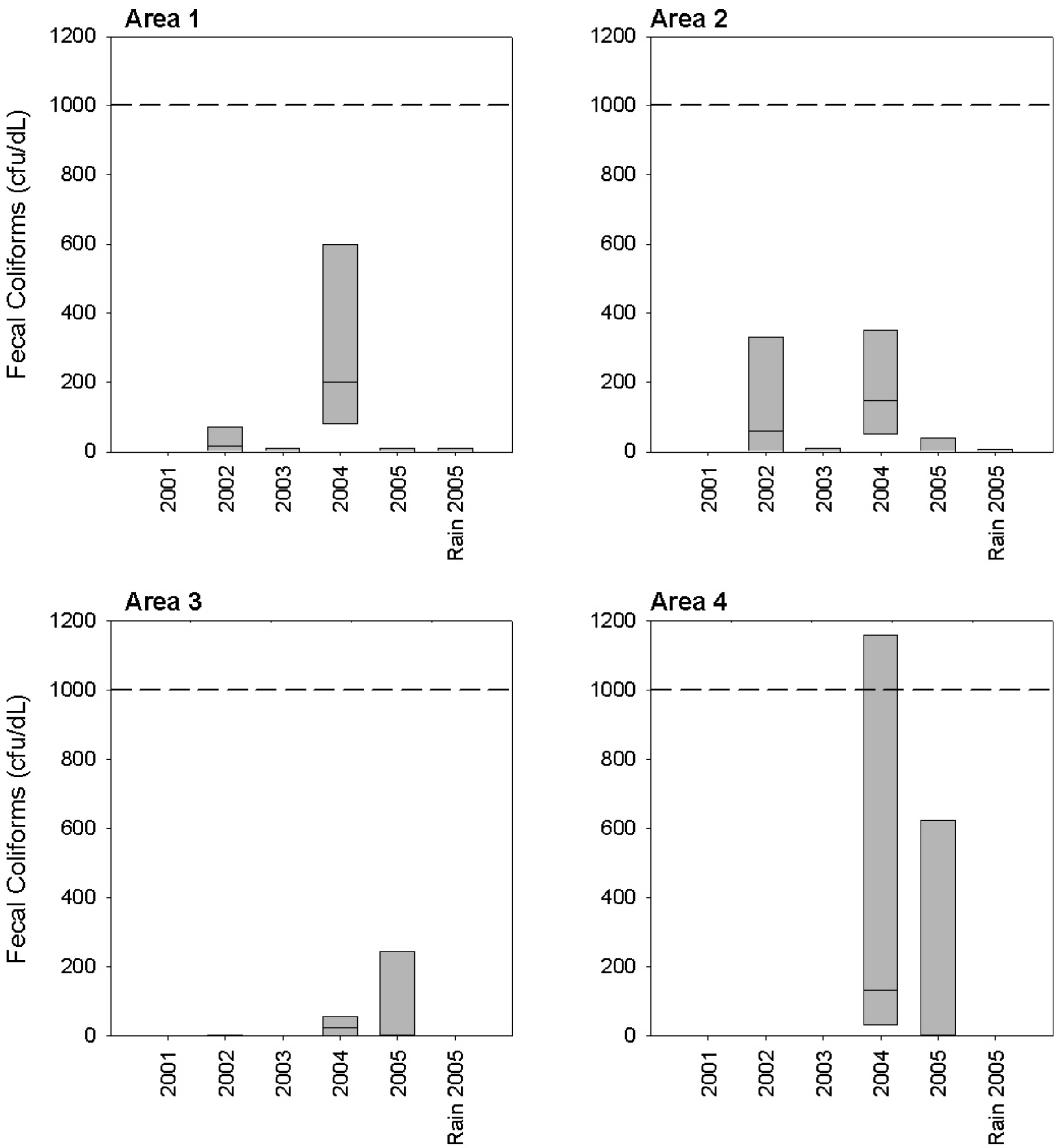

Figure D18. Box plots summarizing fecal coliform counts (colony forming units/100mL) for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent the surface water quality objective.

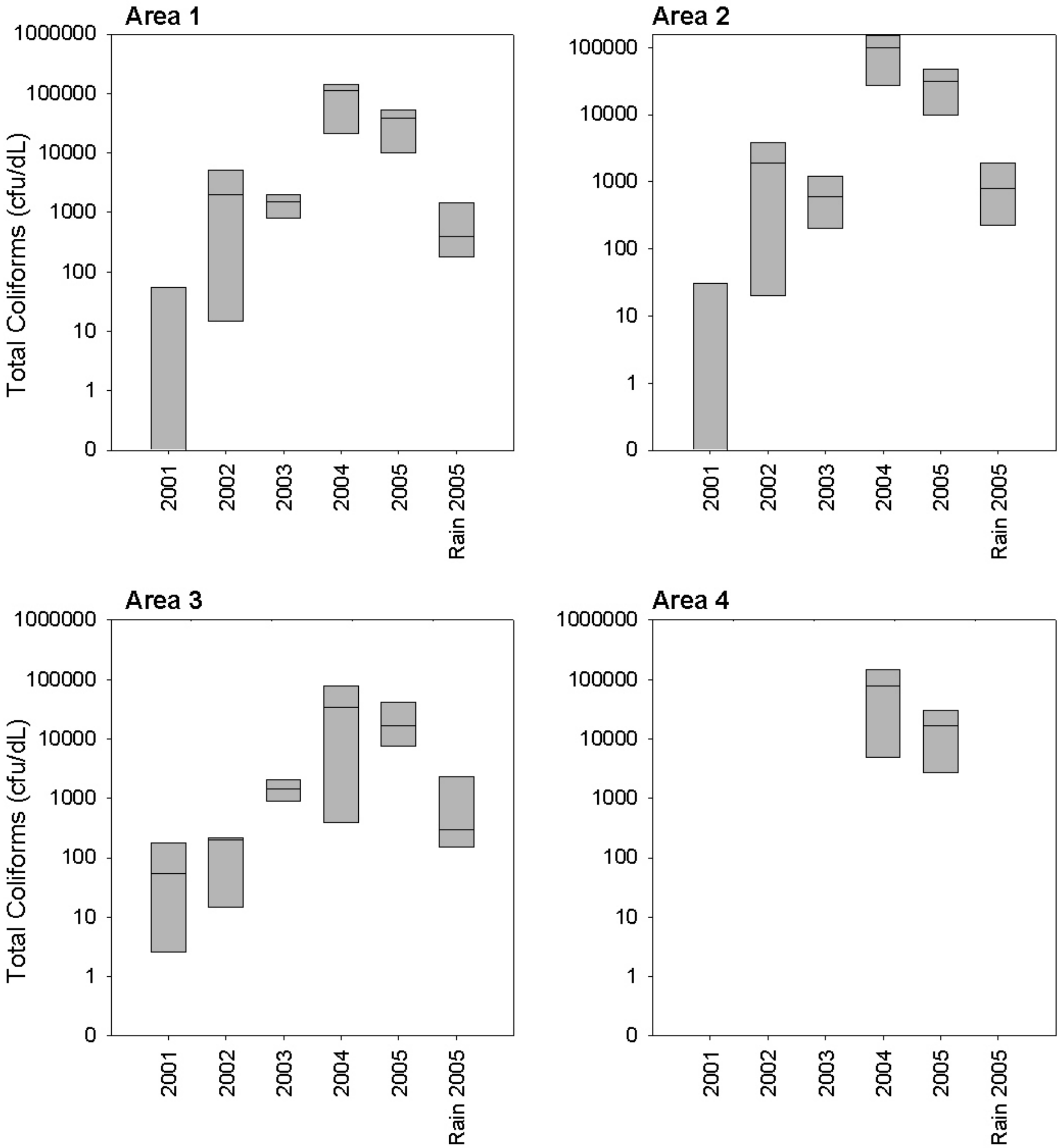

Figure D19. Box plots summarizing total coliform counts (colony forming units/100mL) for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Note the log scale.

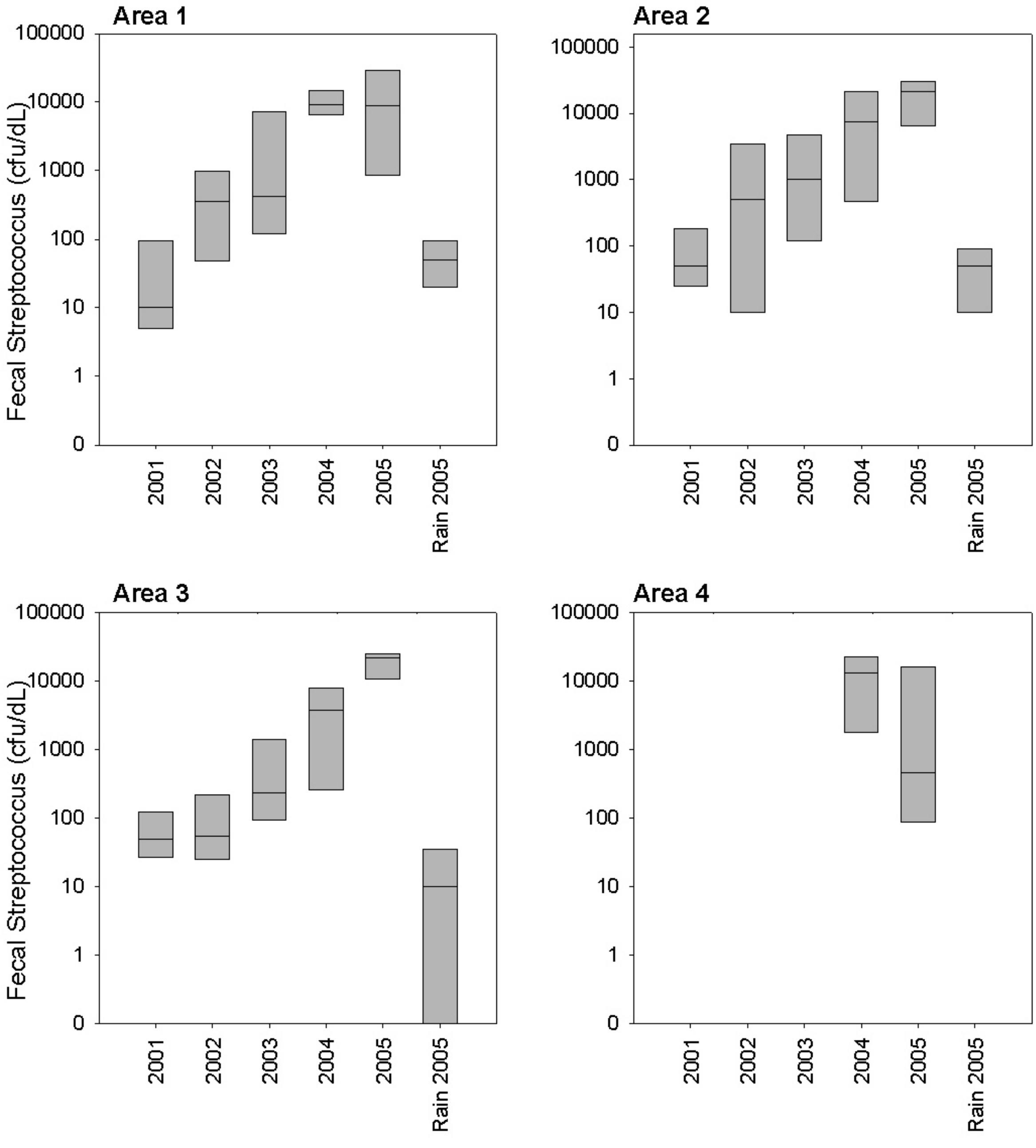

Figure D20. Box plots summarizing fecal streptococcus counts (colony forming units/100mL) for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Note the log scale.

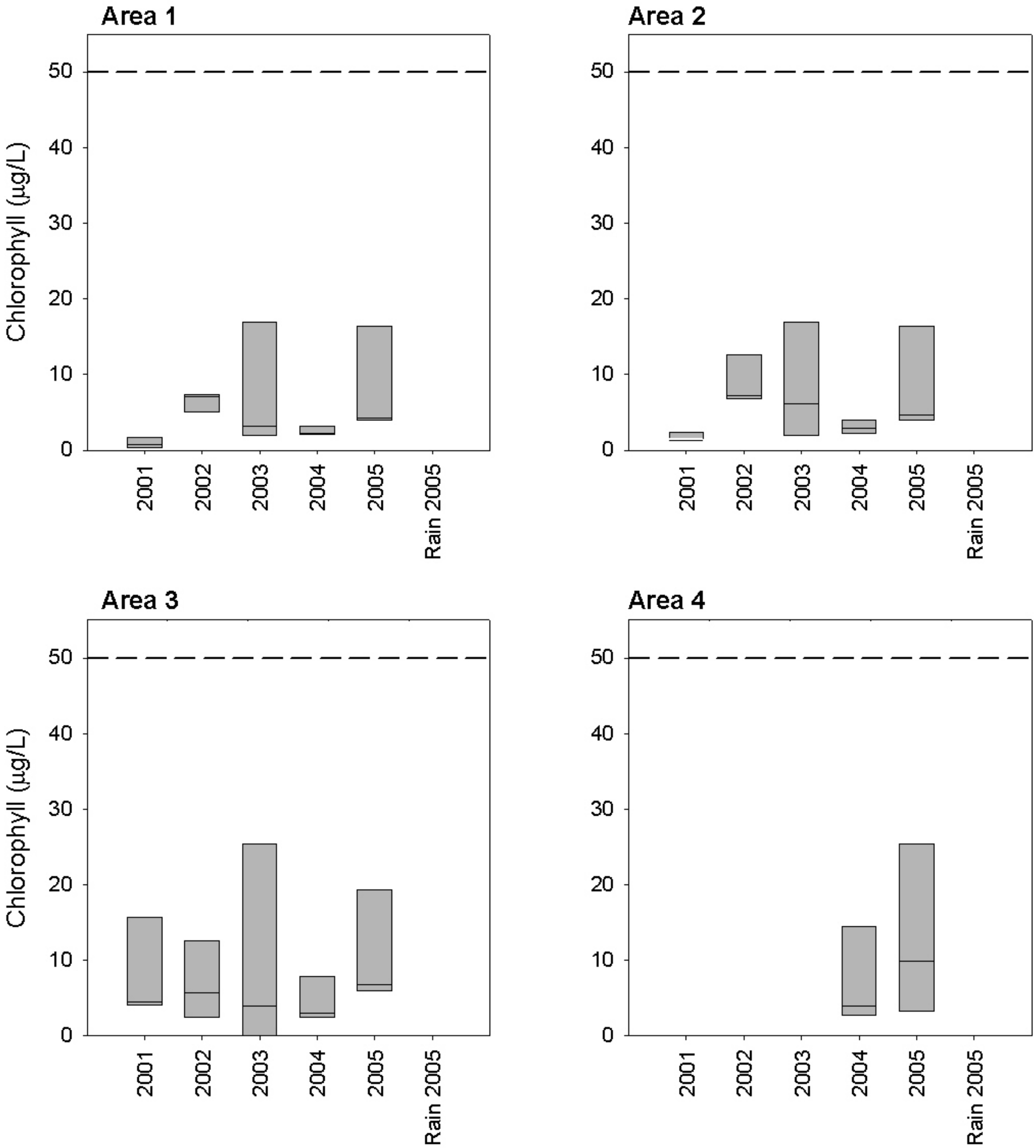

Figure D21. Box plots summarizing chlorophyll values for Spirit Creek watersheds. Boxes are grouped by Area and include all downstream stations. Dashed lines represent the surface water quality objectives that Saskatchewan Watershed Authority uses in its assessment of surface water quality.

Appendix E

Line Plots for Areas 1 – 4 to Show the Special Trend of Various Water Quality Measures

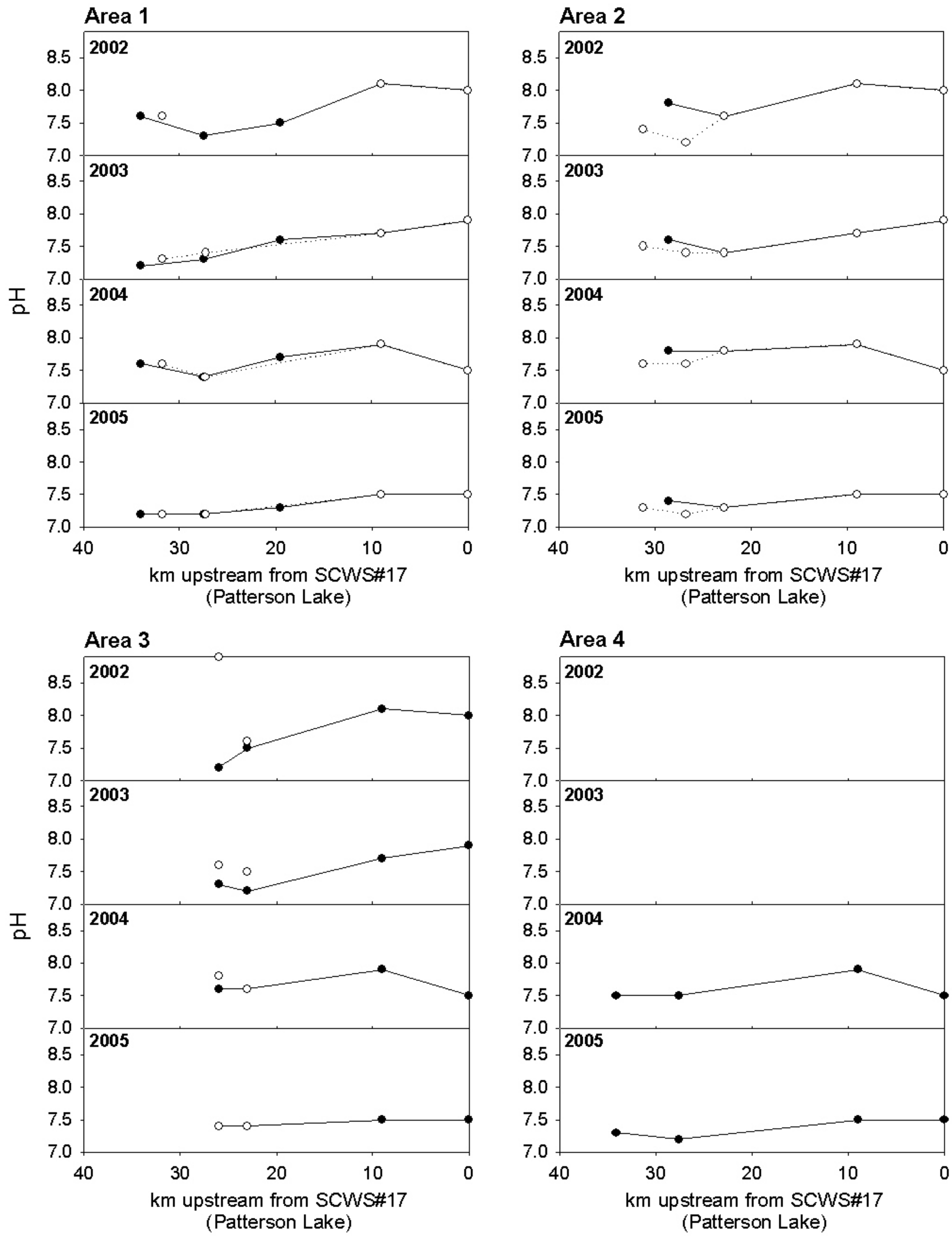

Figure E1. Line plots for Areas 1 - 4 showing the spatial trend of pH in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

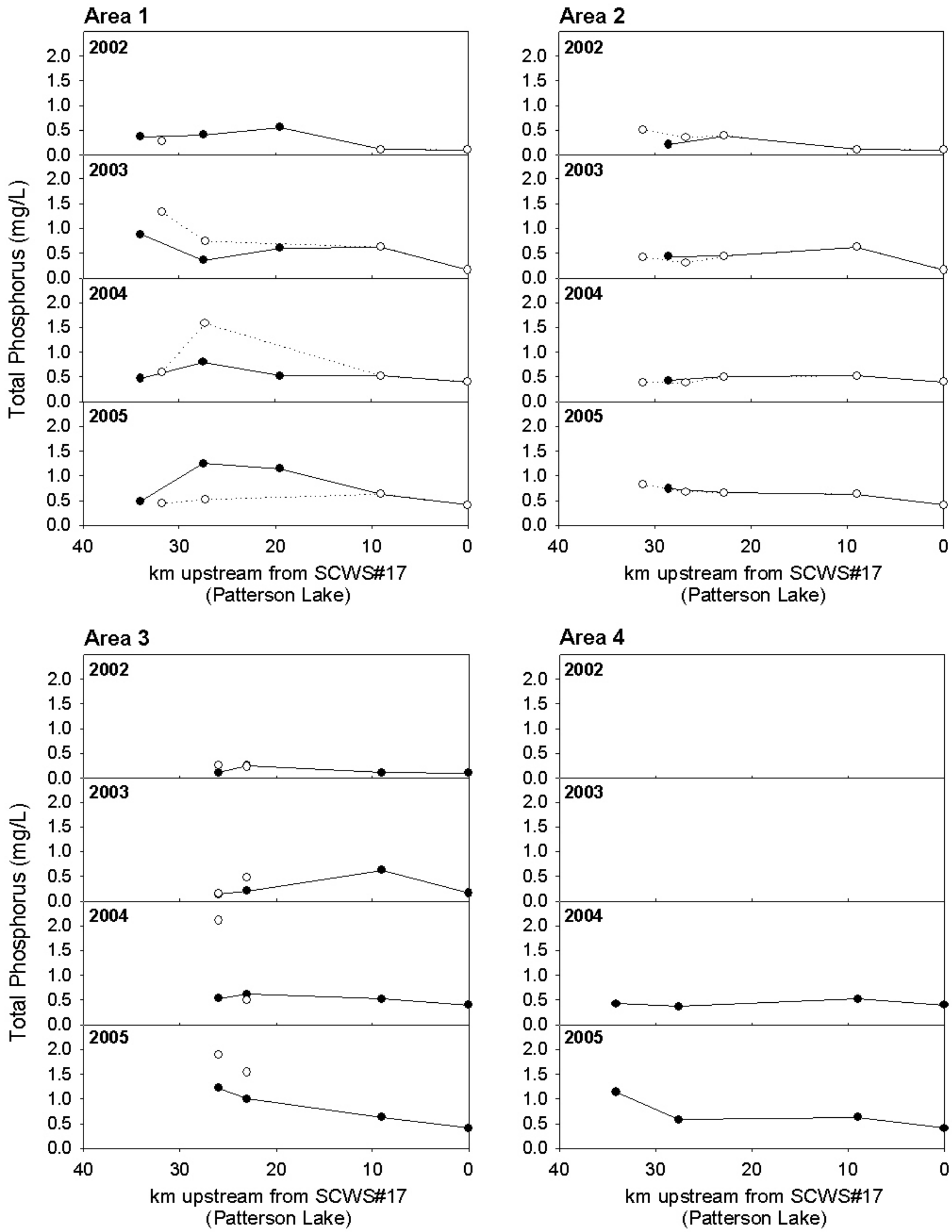

Figure E2. Line plots for Areas 1 - 4 showing the spatial trend of total phosphorus in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

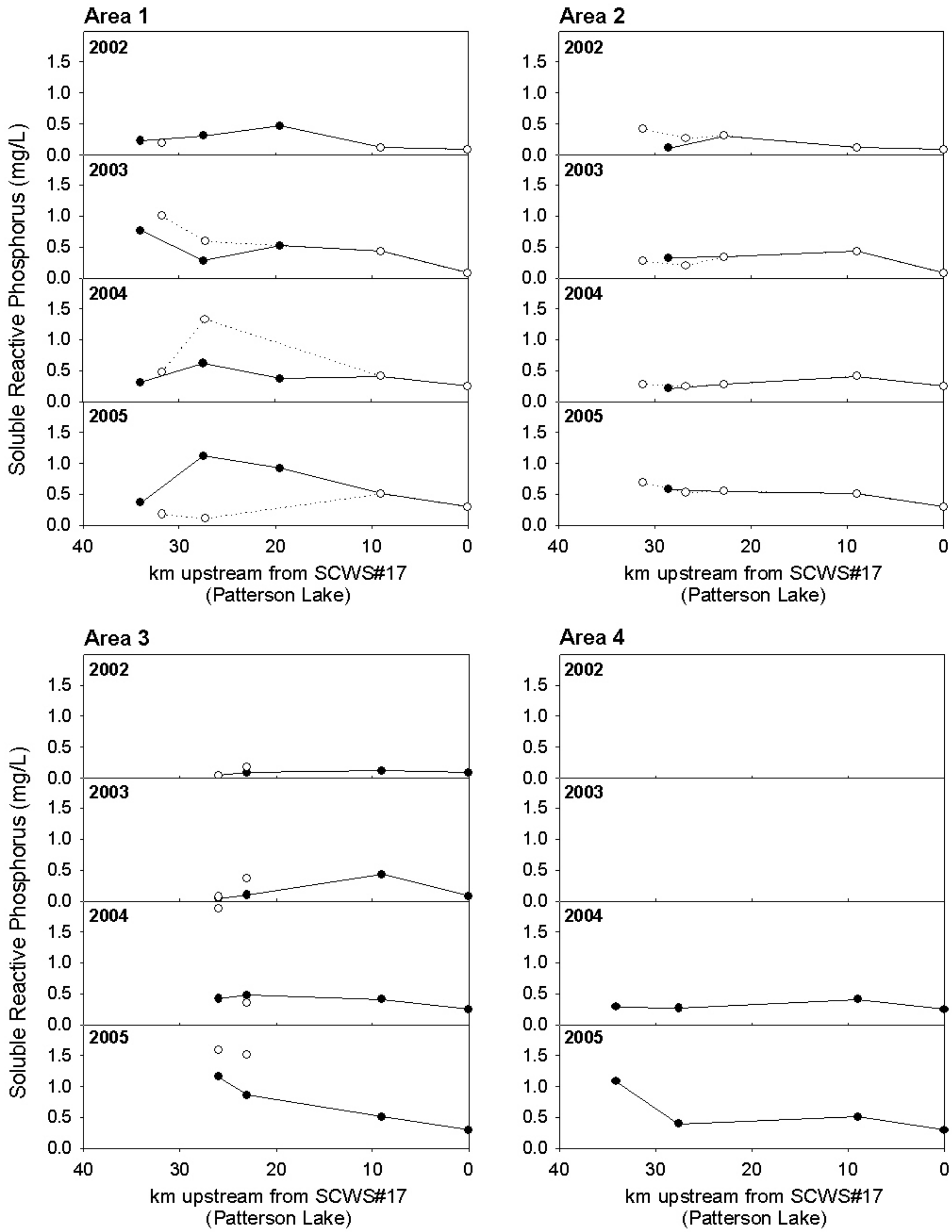

Figure E3. Line plots for Areas 1 - 4 showing the spatial trend of soluble reactive phosphorus (ortho-phosphate) in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

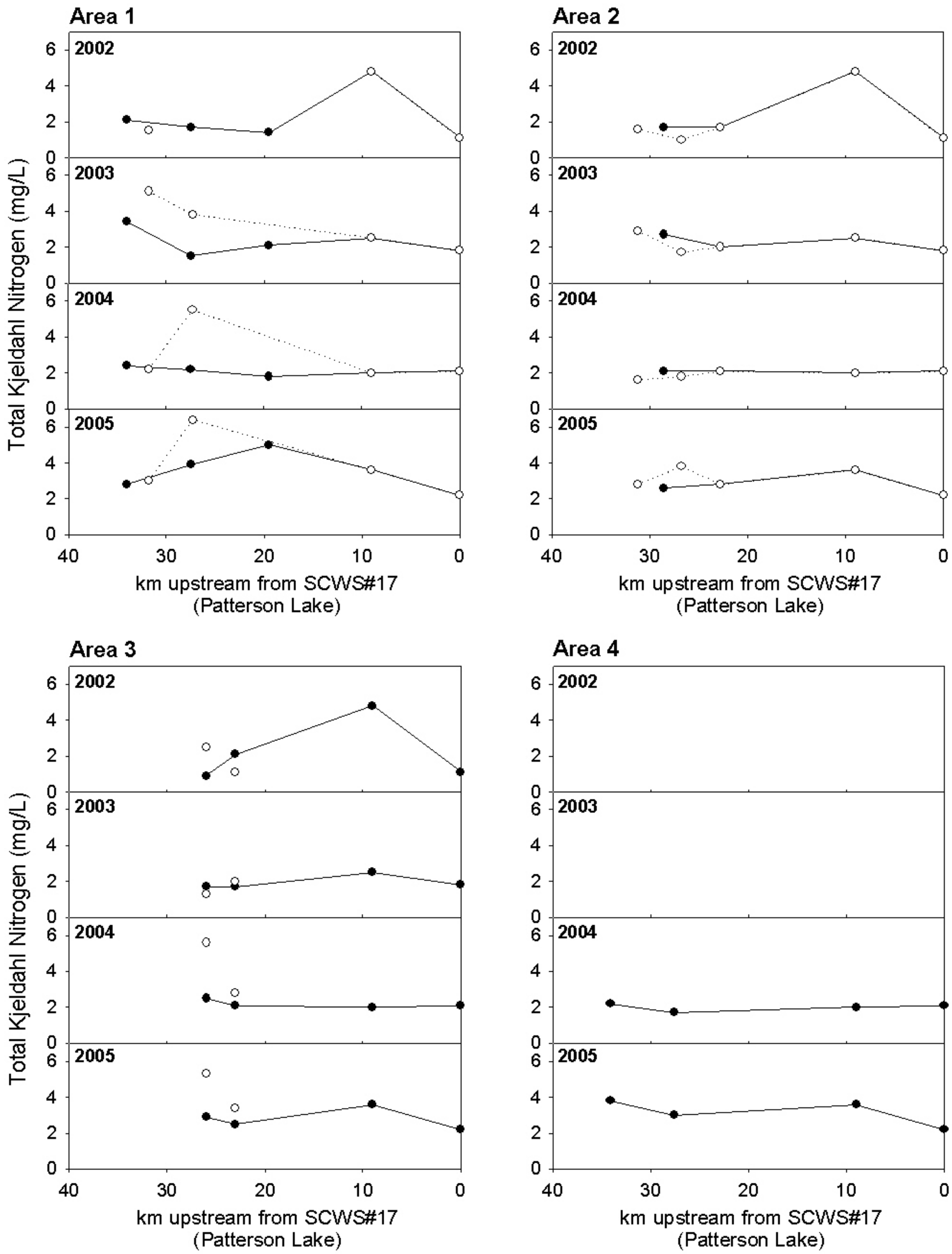

Figure E4. Line plots for Areas 1 - 4 showing the spatial trend of total Kjeldahl nitrogen in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

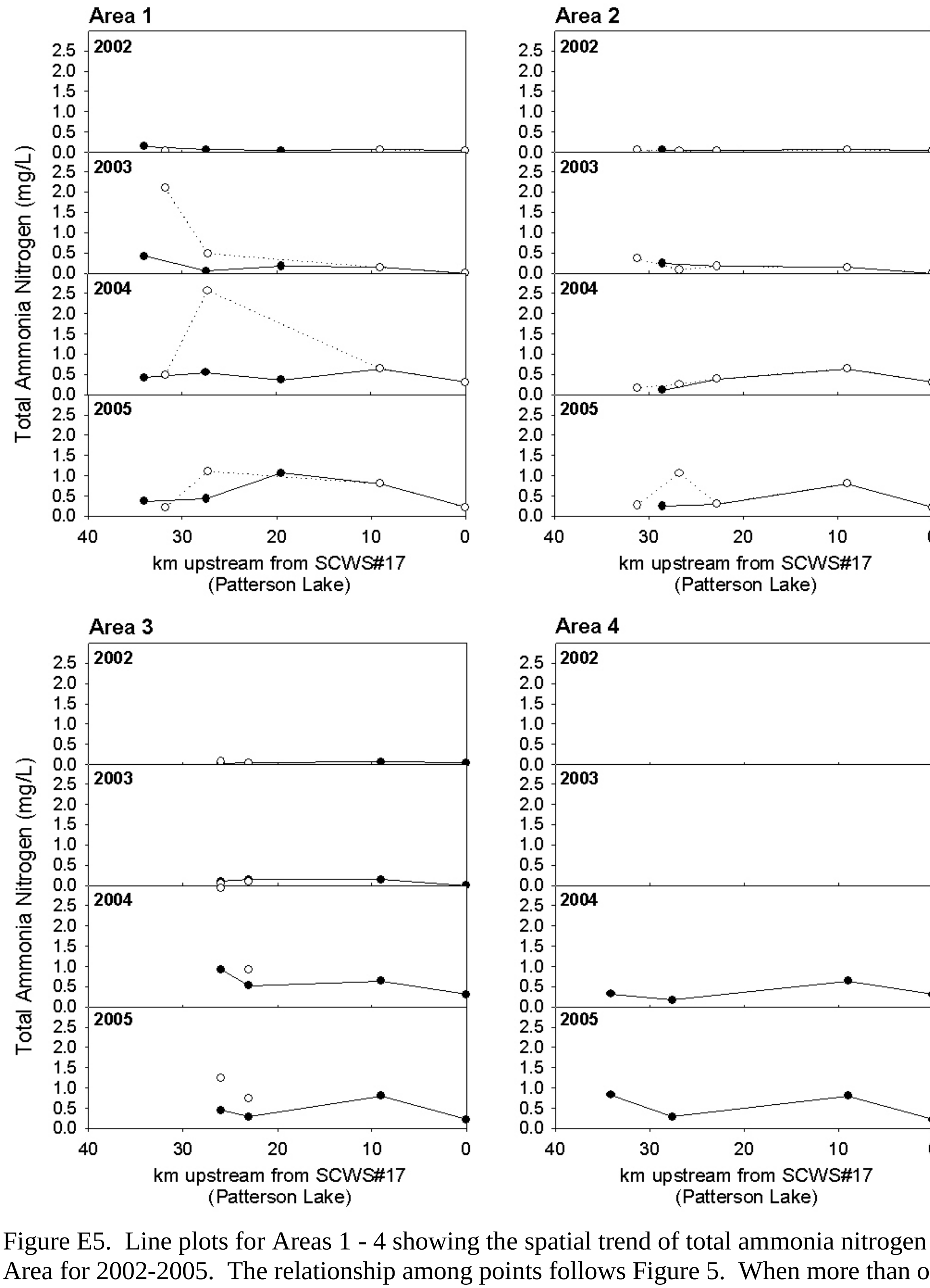

Figure E5. Line plots for Areas 1 - 4 showing the spatial trend of total ammonia nitrogen in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

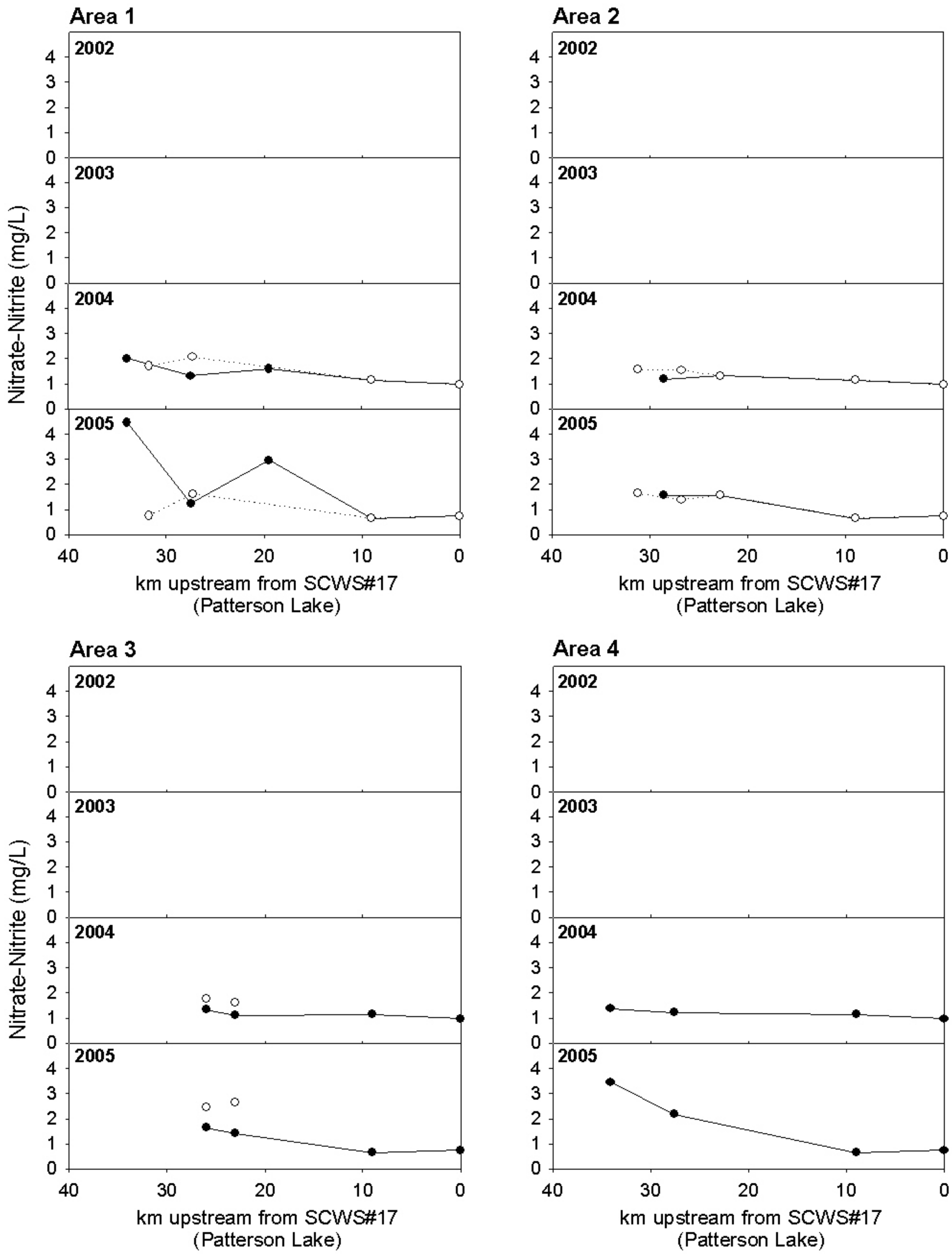

Figure E6. Line plots for Areas 1 - 4 showing the spatial trend of nitrate-nitrite in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

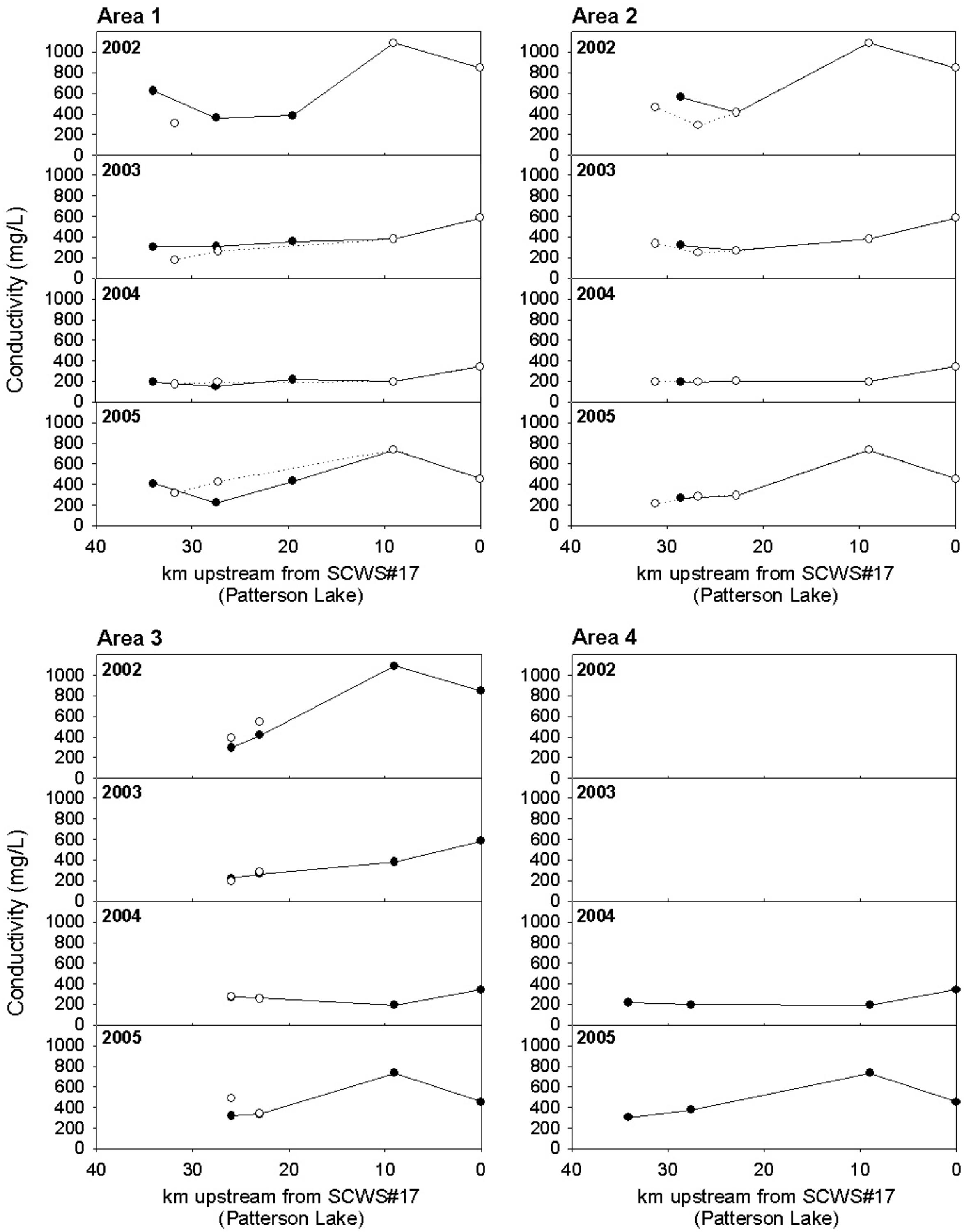

Figure E7. Line plots for Areas 1 - 4 showing the spatial trend of conductivity in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

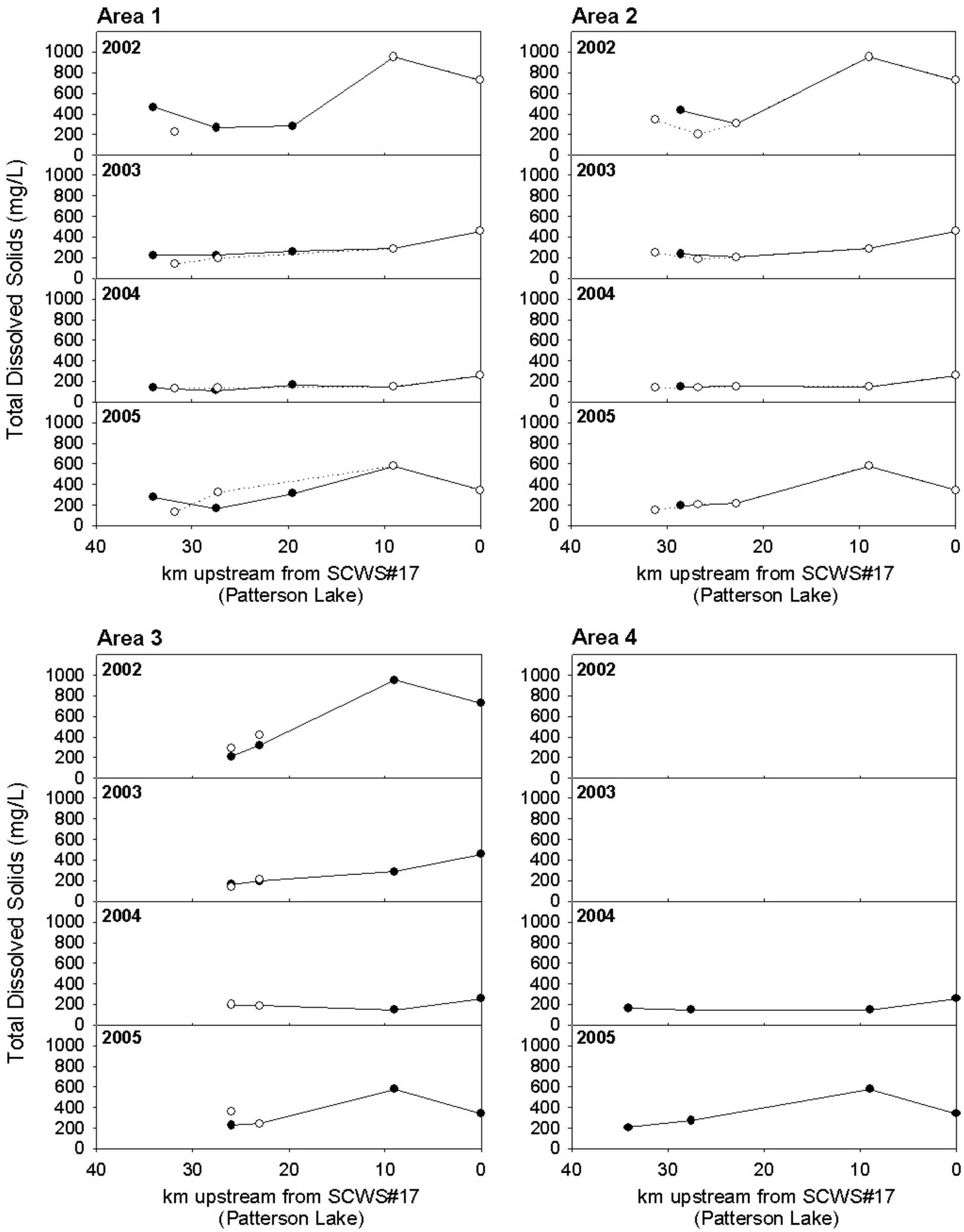

Figure E8. Line plots for Areas 1 - 4 showing the spatial trend of total dissolved solids in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

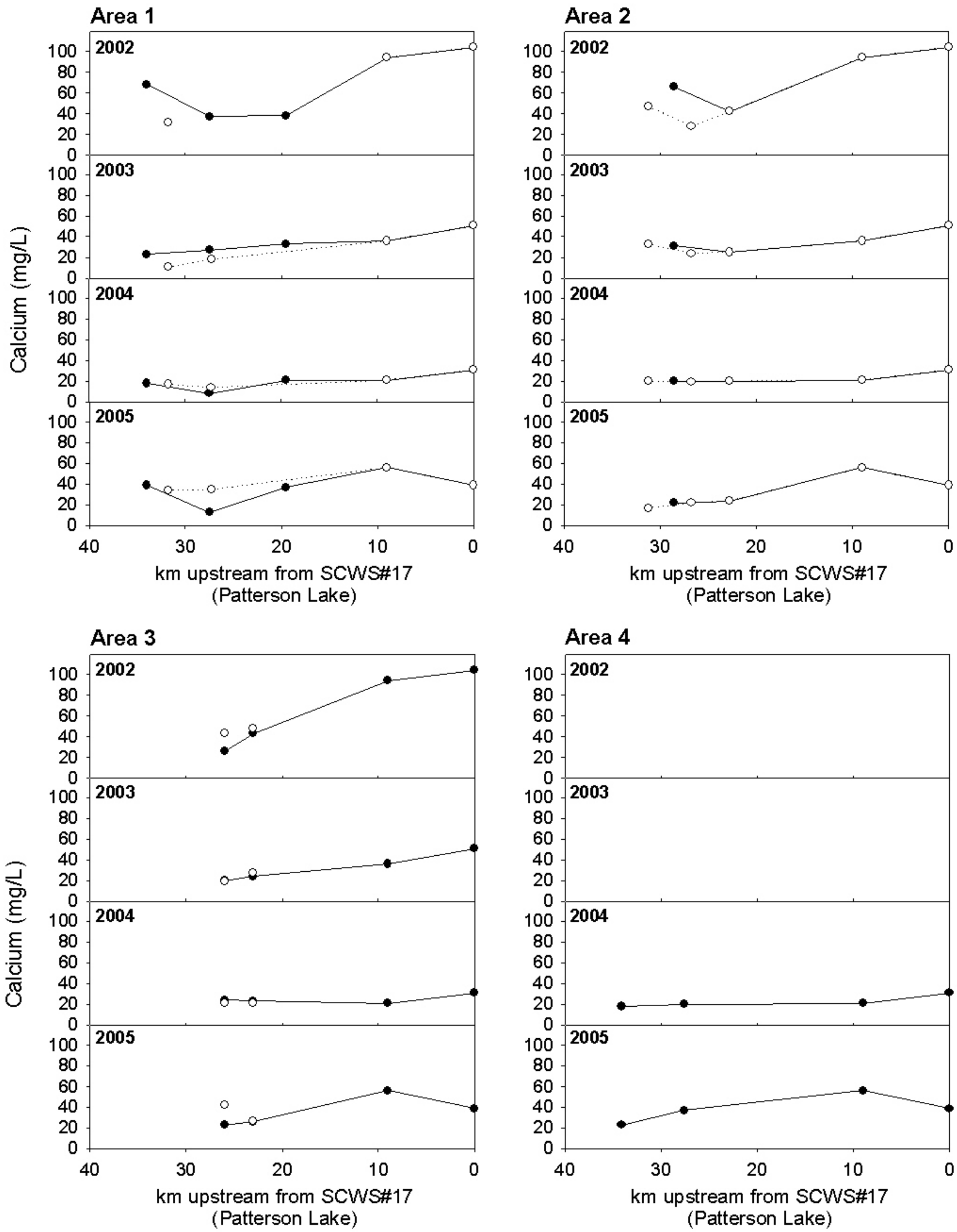

Figure E9. Line plots for Areas 1 - 4 showing the spatial trend of calcium in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

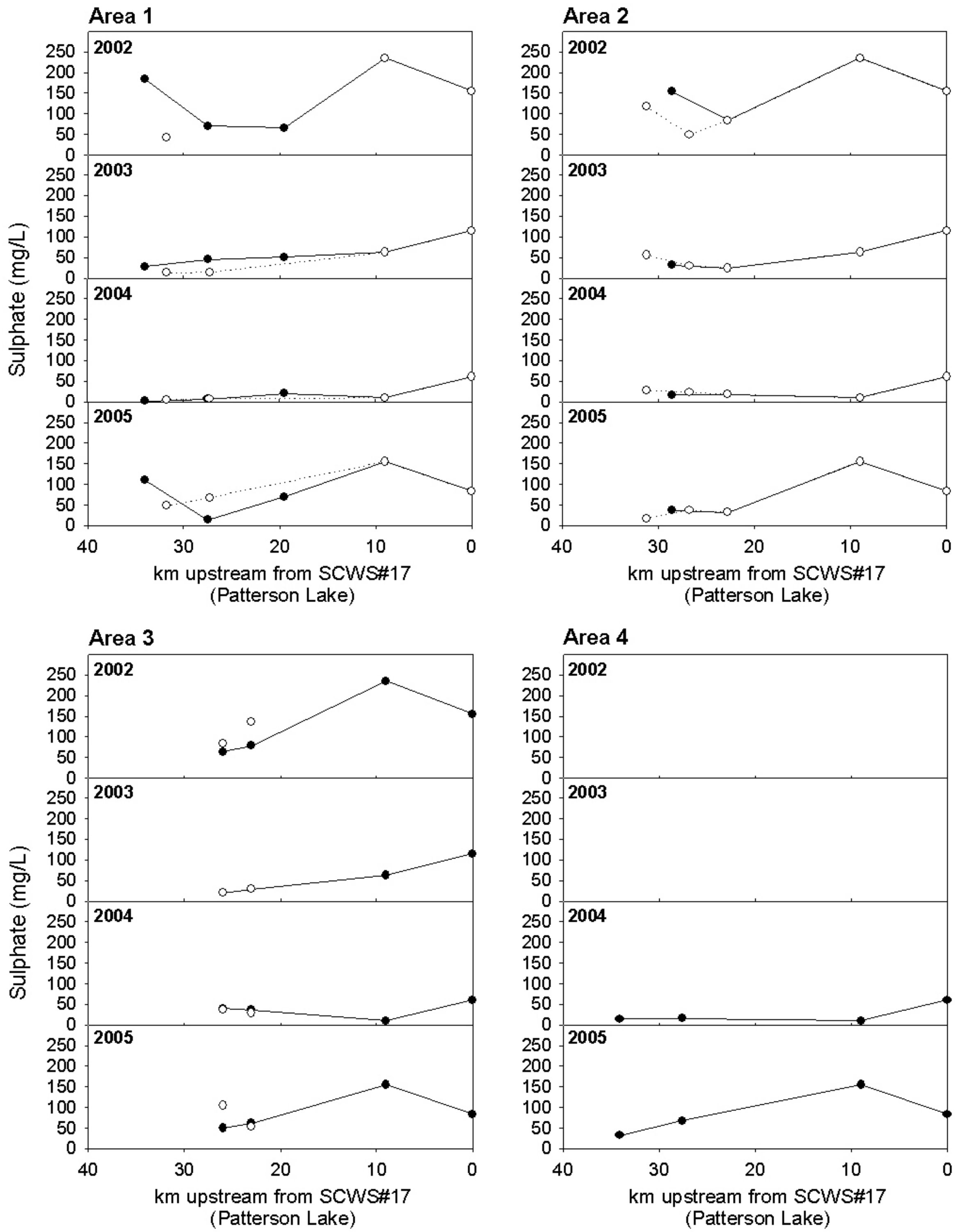

Figure E10. Line plots for Areas 1 - 4 showing the spatial trend of sulphate in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

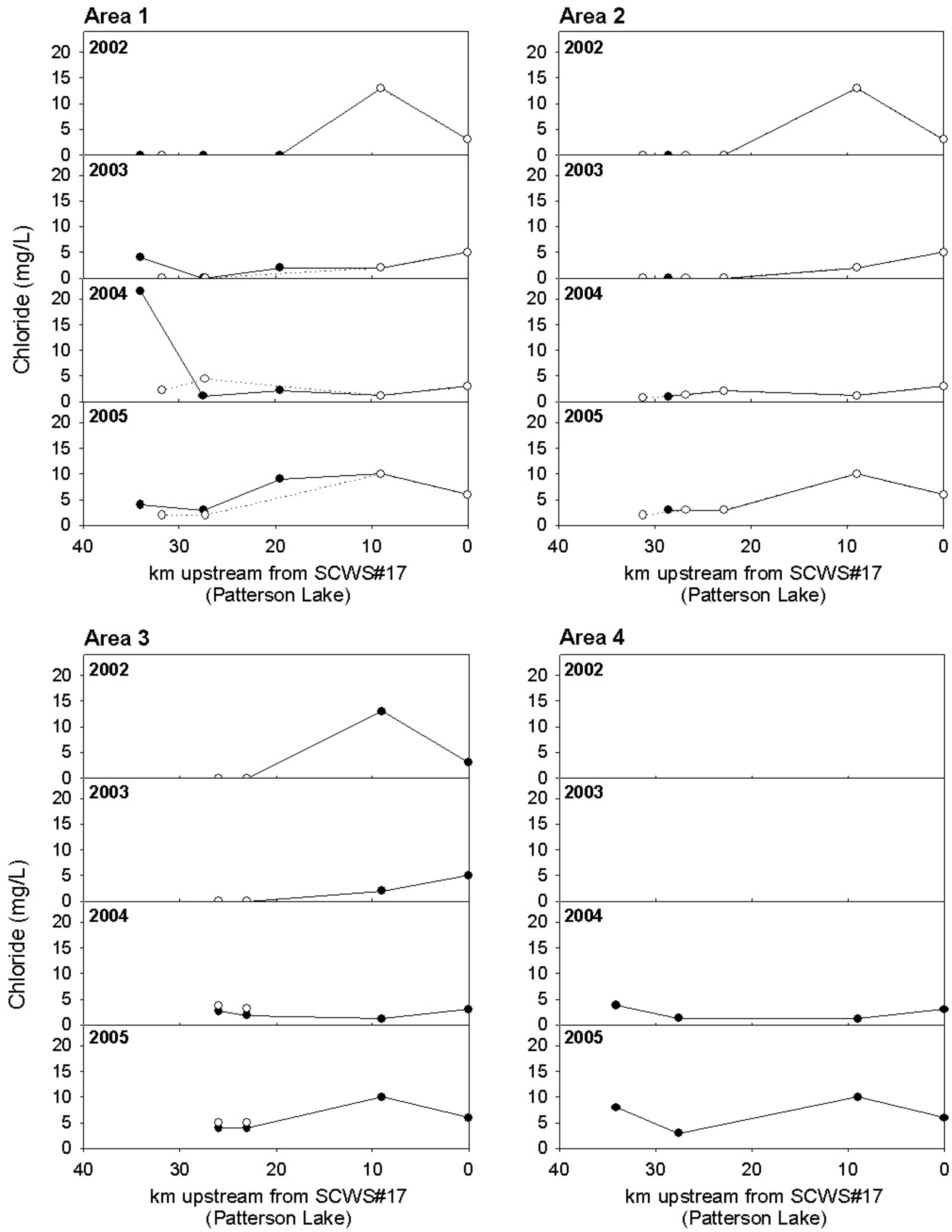

Figure E11. Line plots for Areas 1 - 4 showing the spatial trend of chloride in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

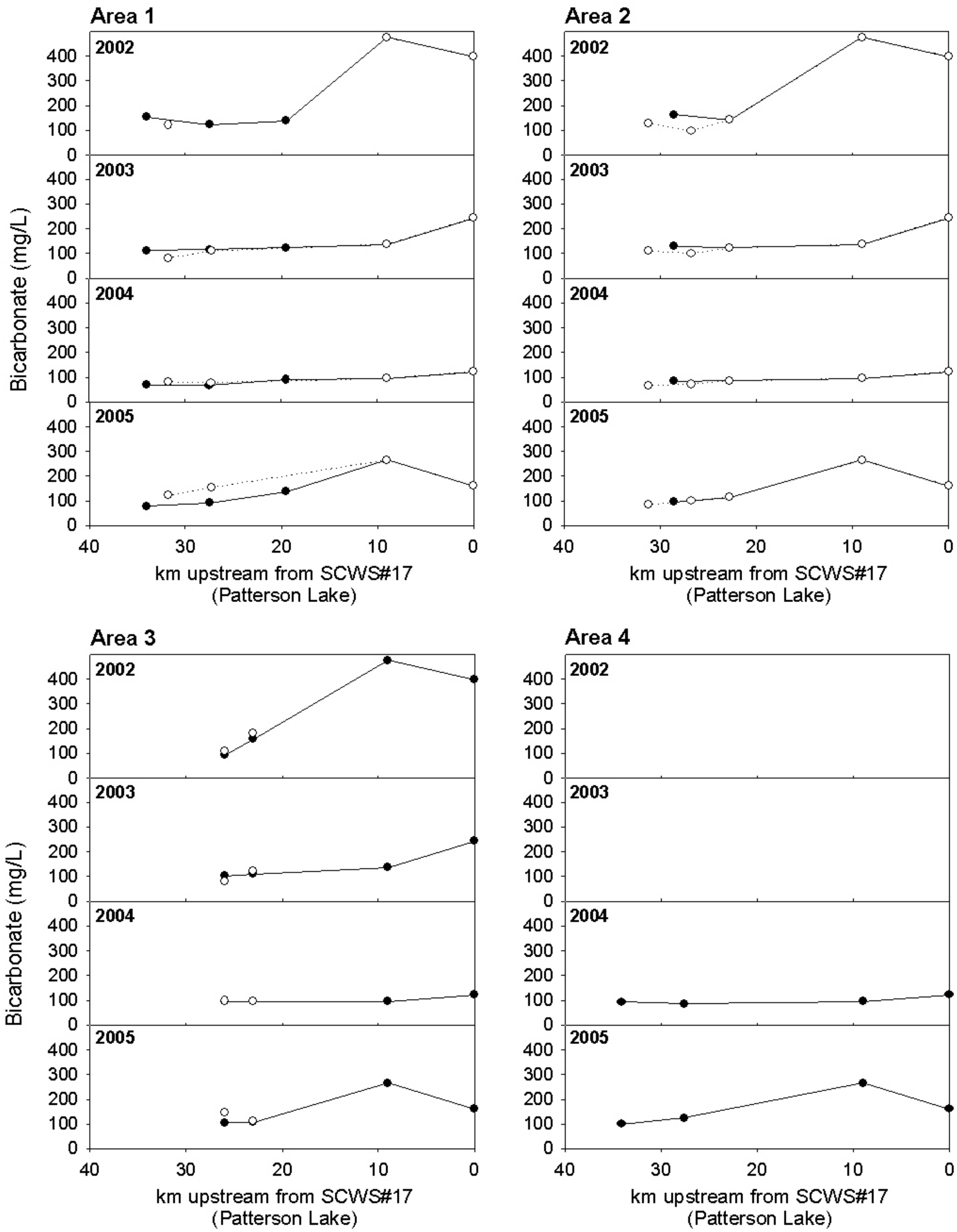

Figure E12. Line plots for Areas 1 - 4 showing the spatial trend of bicarbonate in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

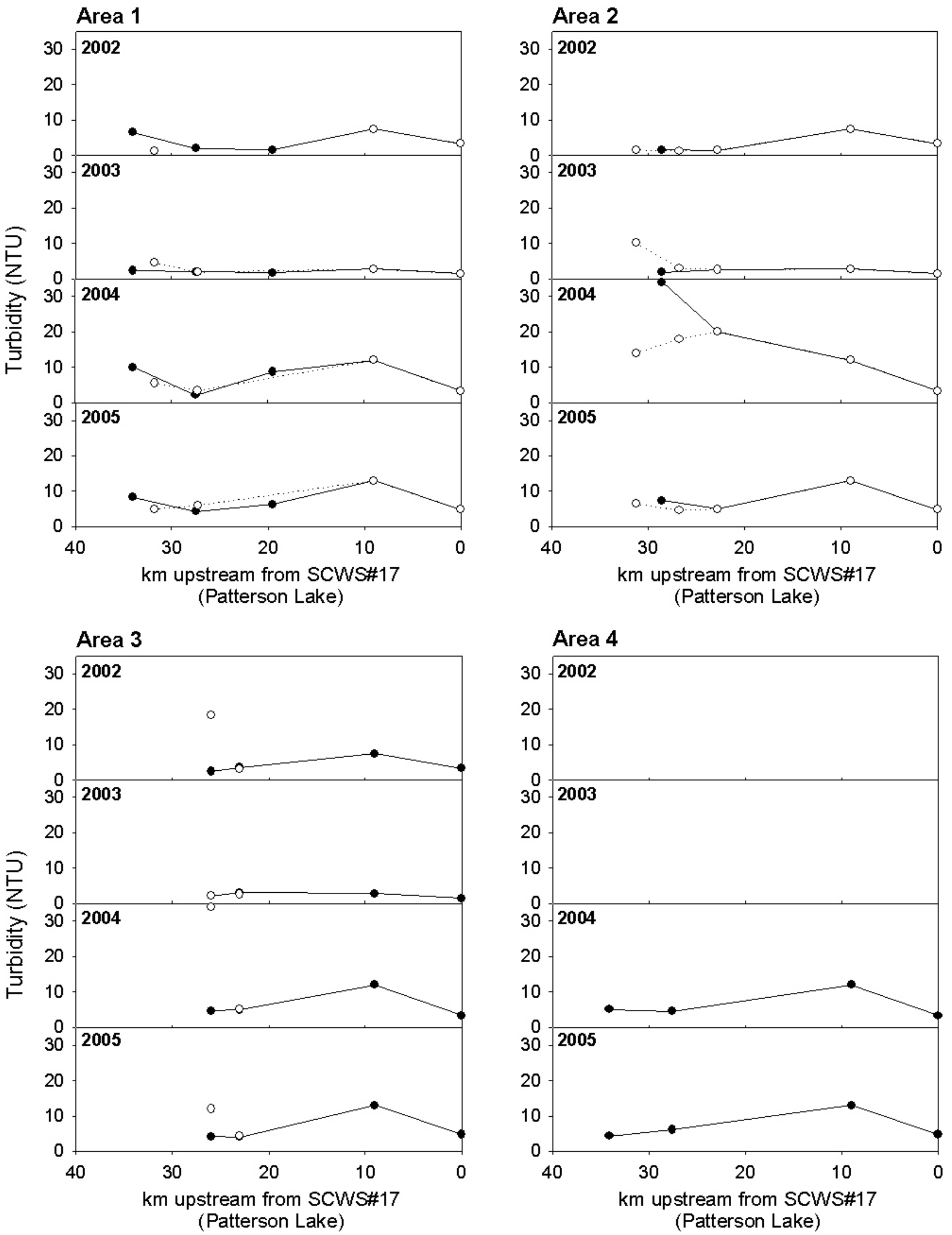

Figure E13. Line plots for Areas 1 - 4 showing the spatial trend of turbidity in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

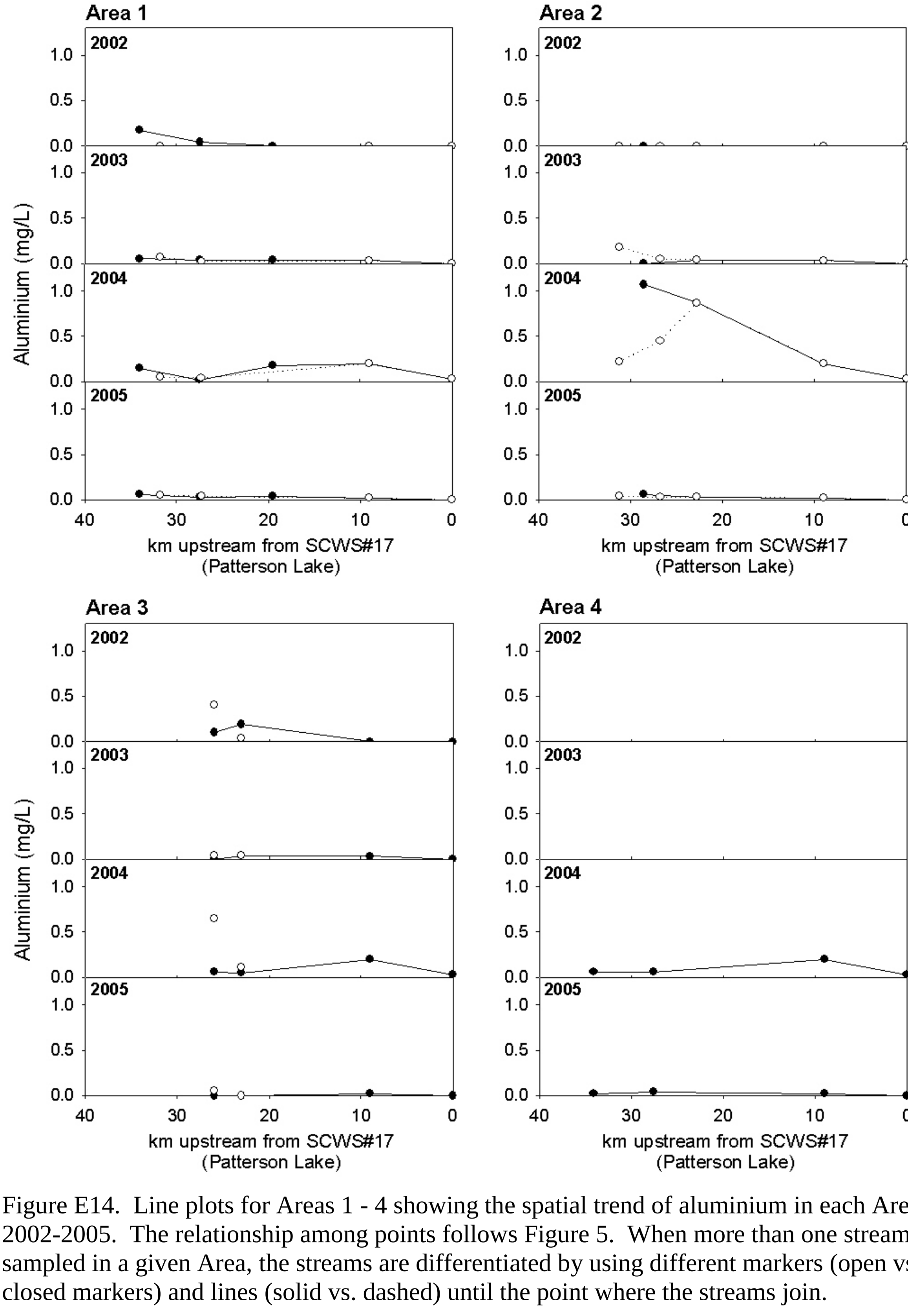

Figure E14. Line plots for Areas 1 - 4 showing the spatial trend of aluminium in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

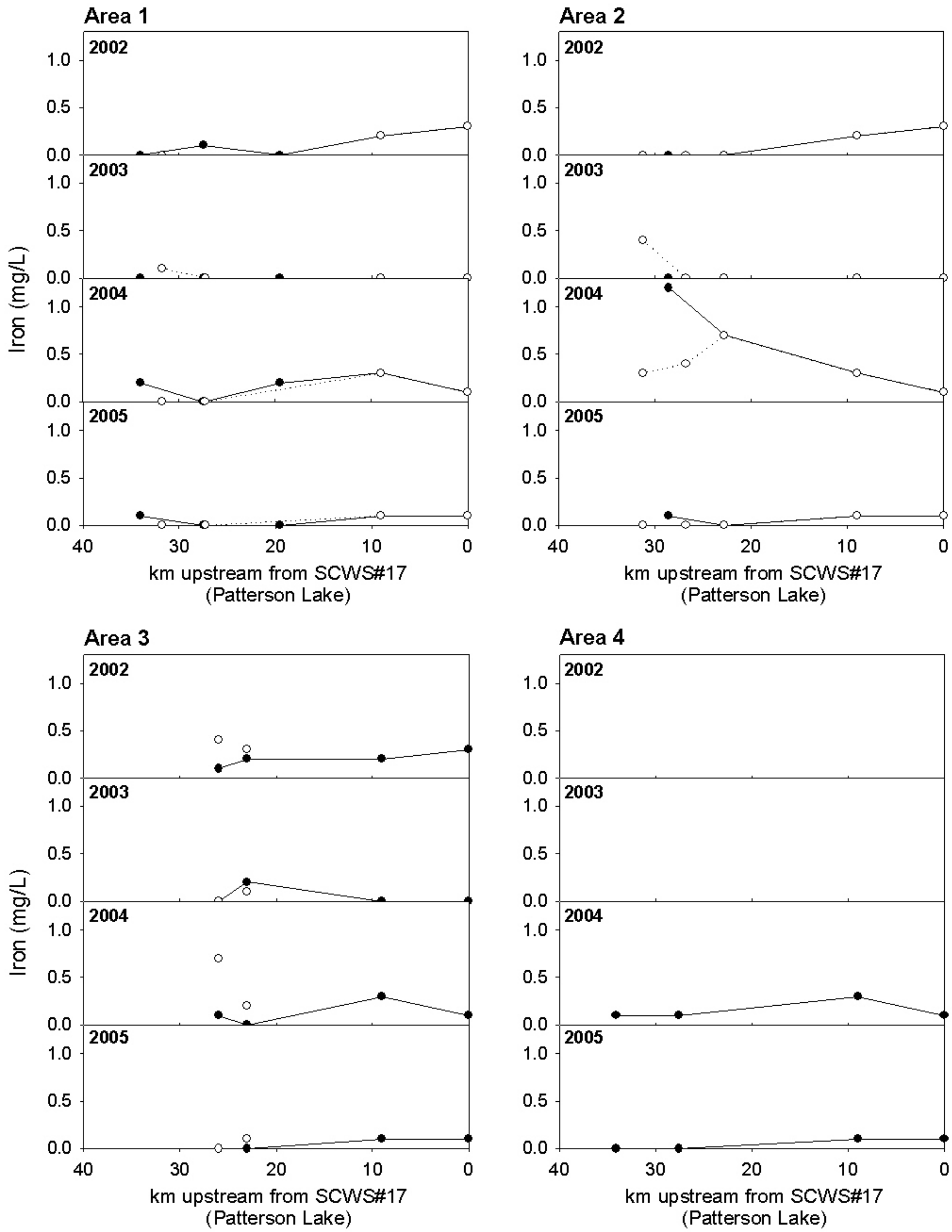

Figure E15. Line plots for Areas 1 - 4 showing the spatial trend of iron in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

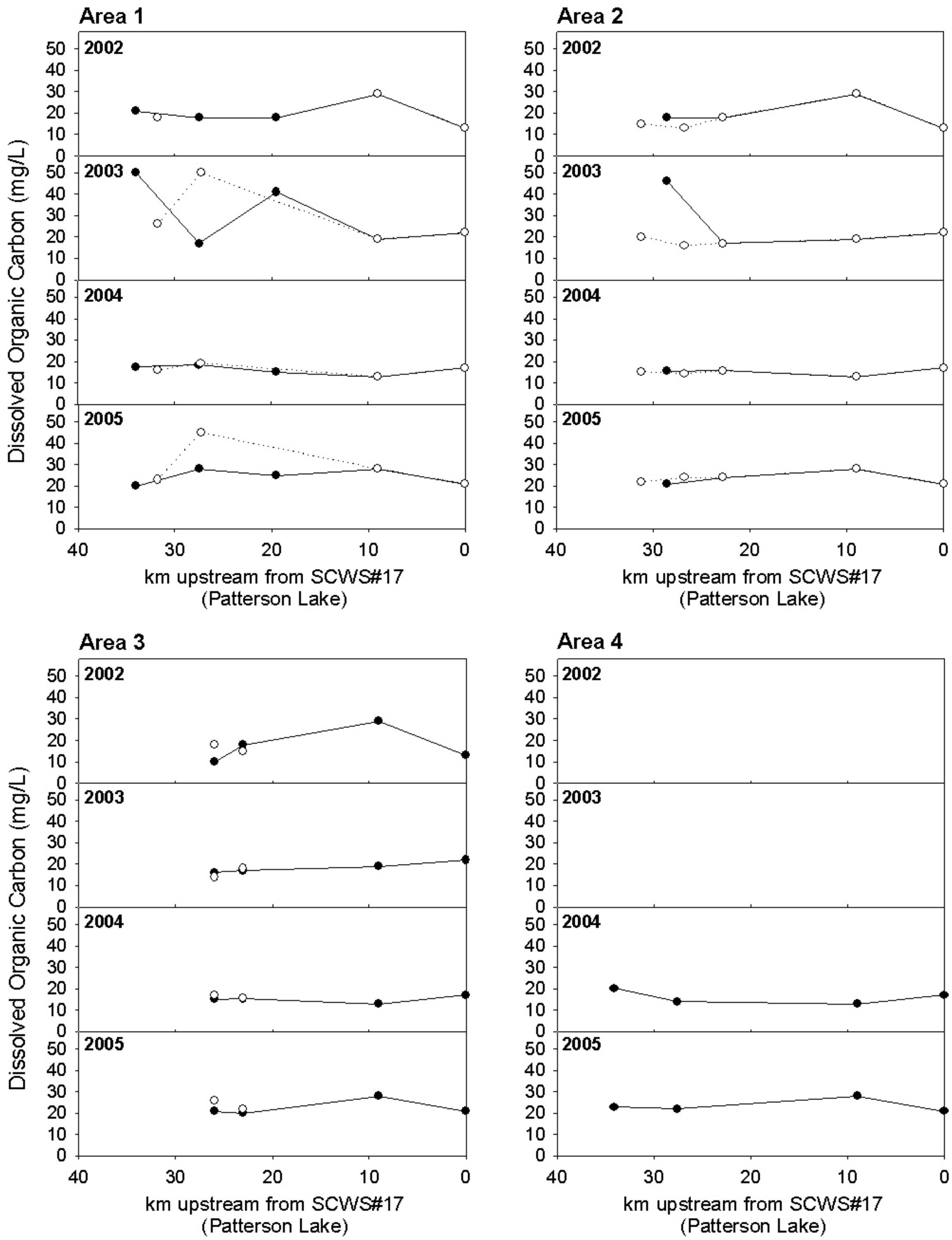

Figure E16. Line plots for Areas 1 - 4 showing the spatial trend of dissolved organic carbon in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

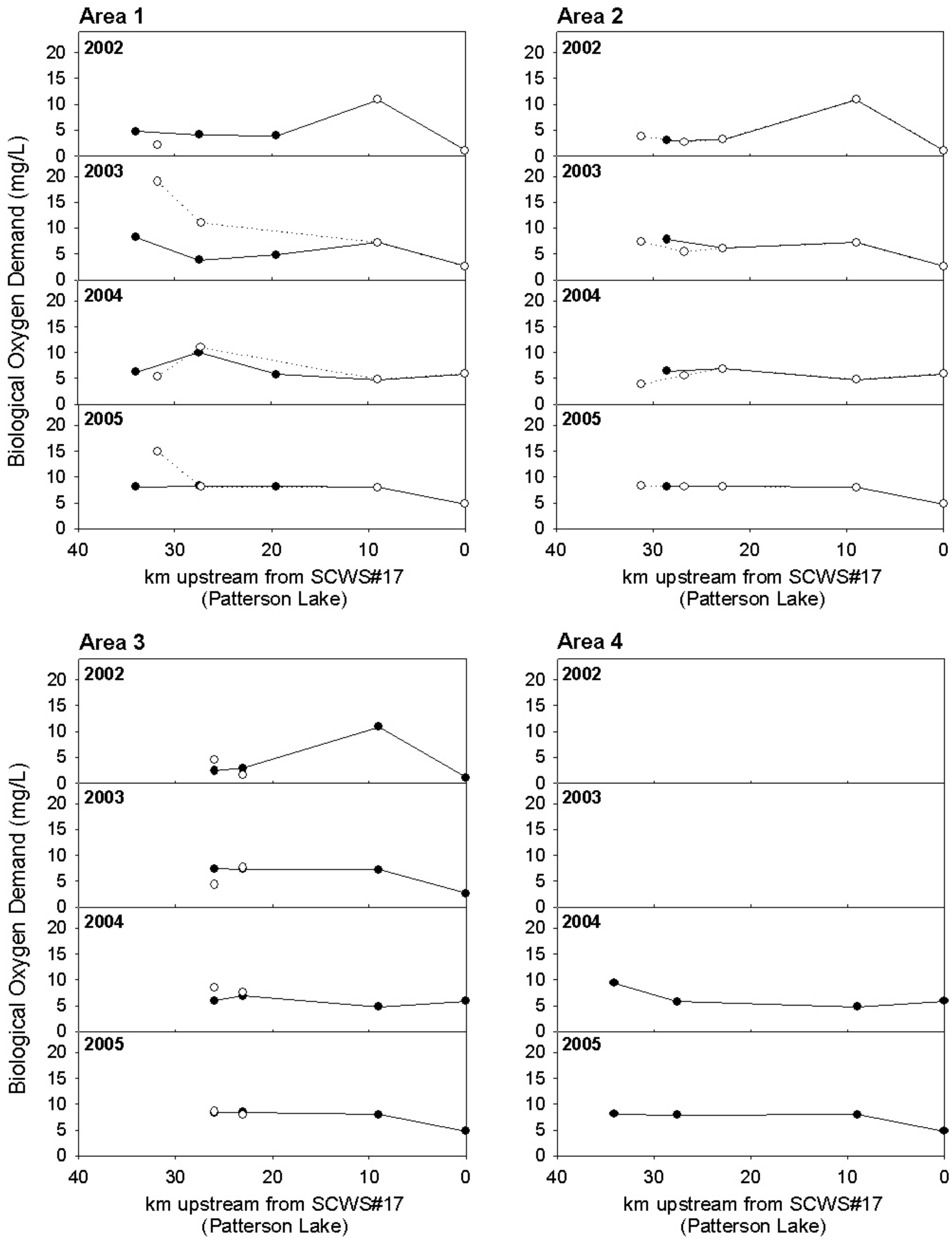

Figure E17. Line plots for Areas 1 - 4 showing the spatial trend of biological oxygen demand in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

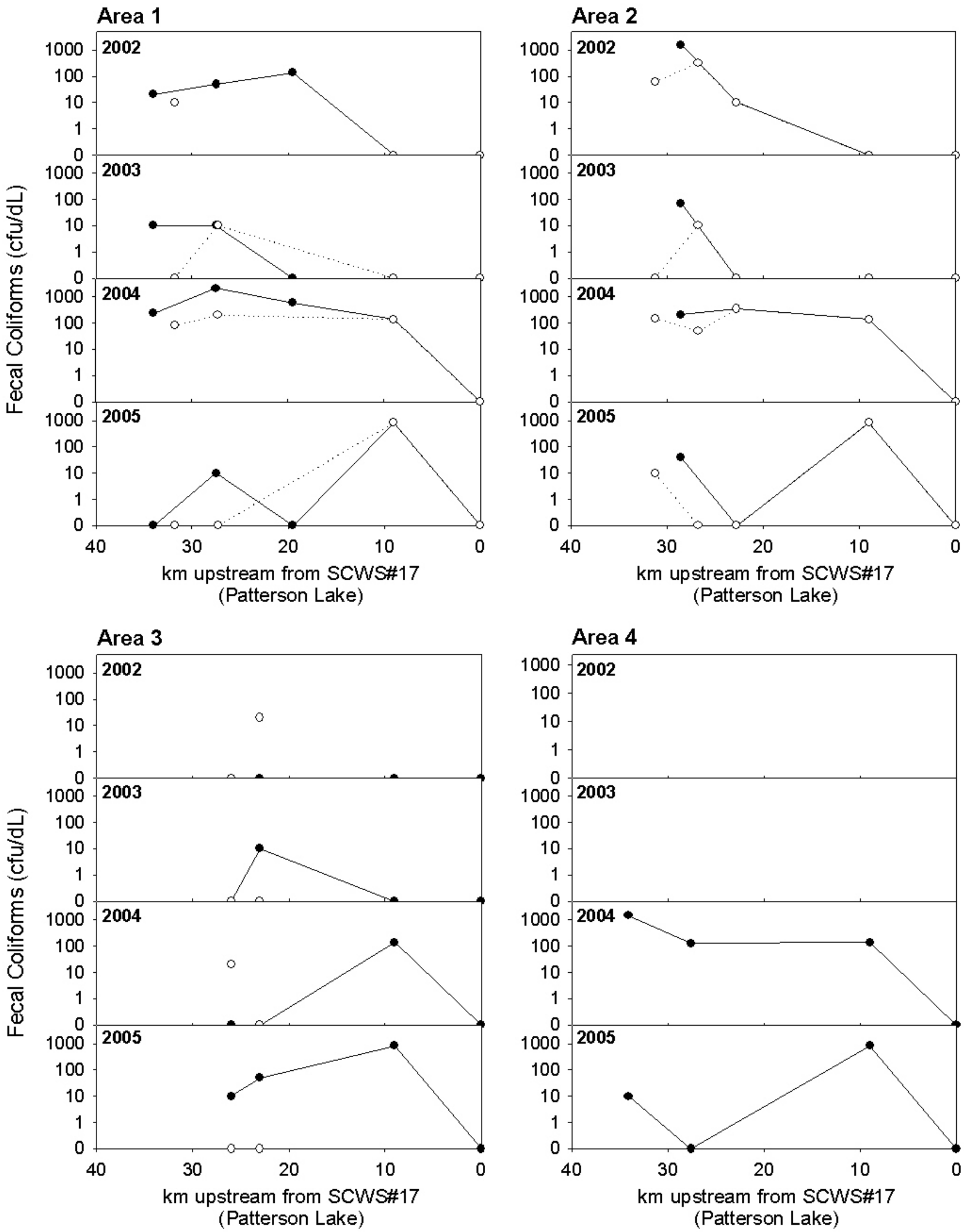

Figure E18. Line plots for Areas 1 - 4 showing the spatial trend of fecal coliform counts in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join. Note the log scale.

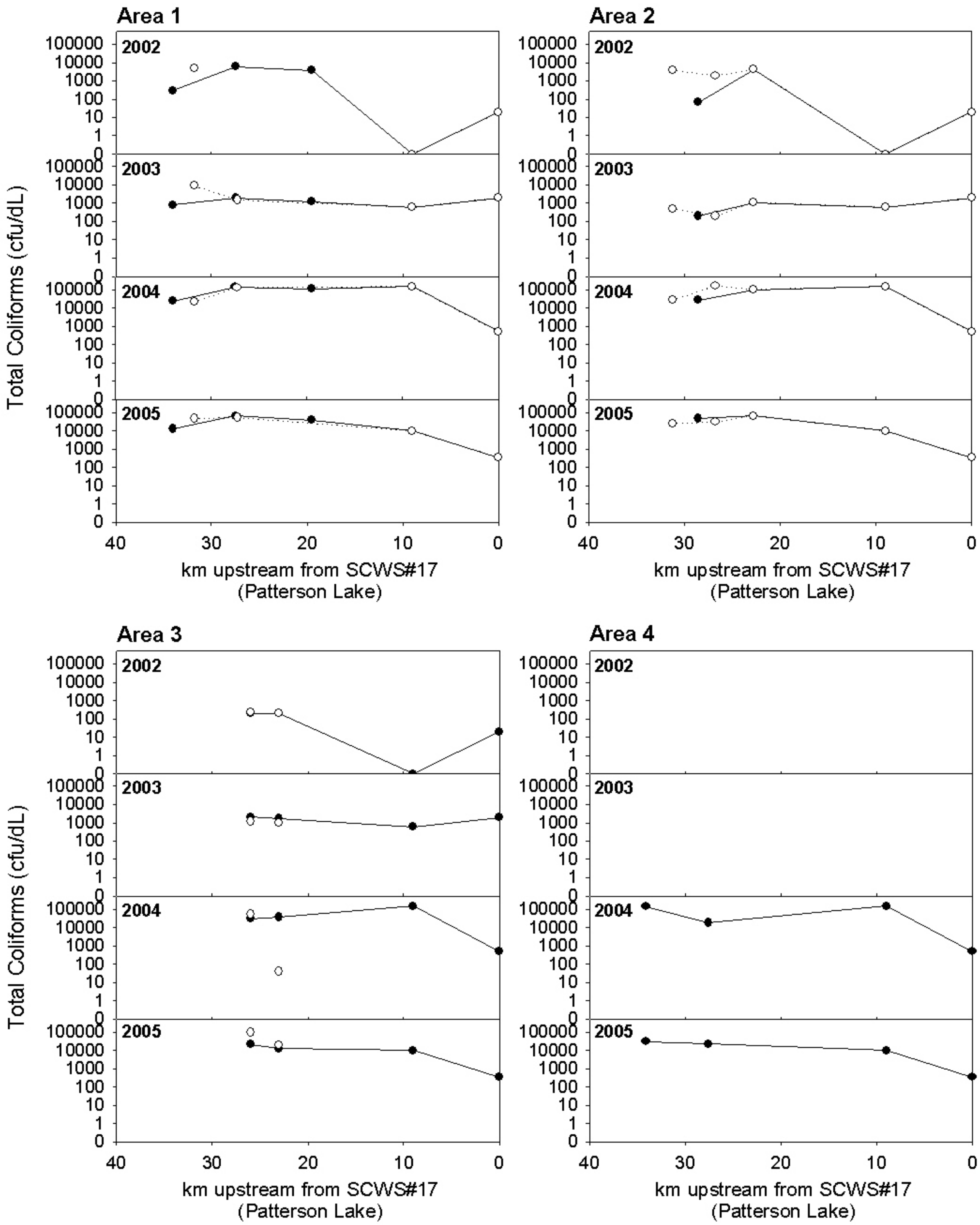

Figure E19. Line plots for Areas 1 - 4 showing the spatial trend of total coliform counts in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join. Note the log scale.

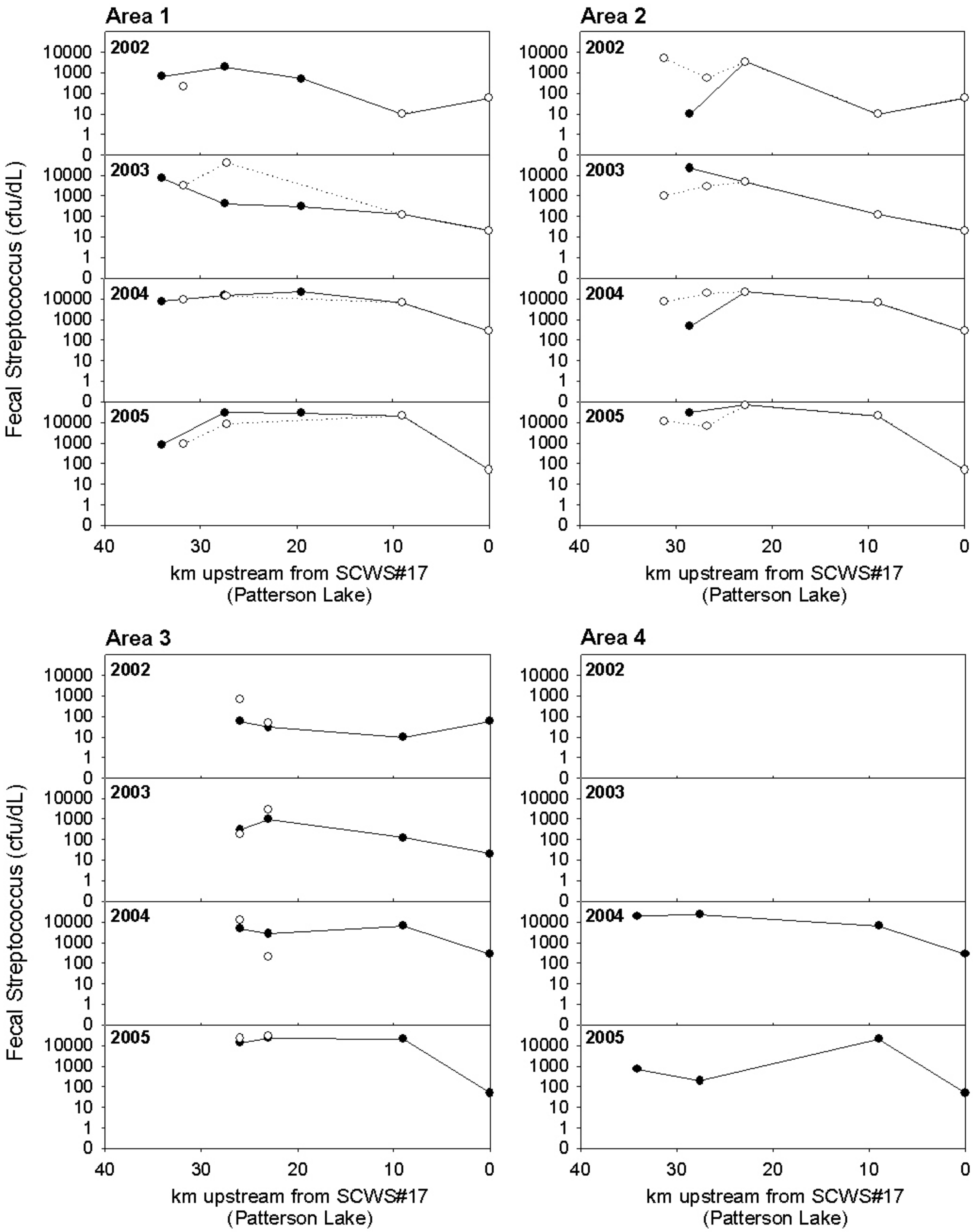

Figure E20. Line plots for Areas 1 - 4 showing the spatial trend of fecal streptococcus counts in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join. Note the log scale.

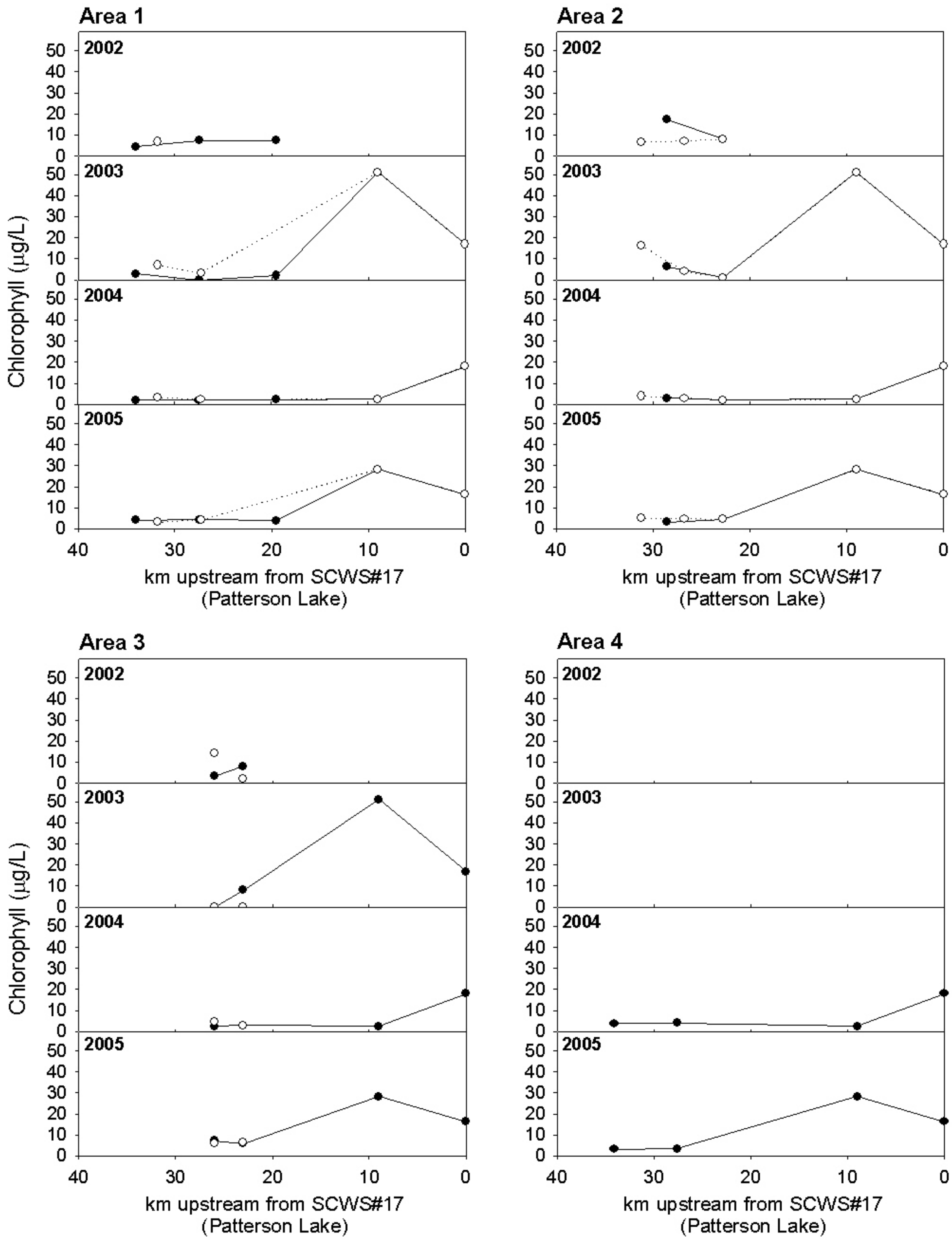

Figure E21. Line plots for Areas 1 - 4 showing the spatial trend of chlorophyll in each Area for 2002-2005. The relationship among points follows Figure 5. When more than one stream was sampled in a given Area, the streams are differentiated by using different markers (open vs. closed markers) and lines (solid vs. dashed) until the point where the streams join.

Appendix F

Water Quality Index Objectives for Source Water Protection (Saskatchewan Watershed Authority 2006)

Parameter	Objective
Total Arsenic (µg/L)	5
Dissolved Chloride (mg/L)	100
Total Chromium (µg/L)	1
Mercury (µg/L)	0.026
Unionized Ammonia (mg/L)	19
Dissolved Oxygen (mg/L)	5.5
pH (units)	6.5-9.0
Dissolved Sodium (mg/L)	100
2’4-D (µg/L)	4
MCPA (µg/L)	0.025
Total Aluminium (µg/L)	100
Sulphate (mg/L)	500
Fecal Coliform Bacteria (orgs/100mL)*	1,000
Total Phosphorous (mg/L)	0.1
Dissolved Nitrate & Nitrite (mg/L)	1
Chlorophyll *a* (µg/L)*	50

*Chlorophyll *a* is for lakes only; fecal coliform bacteria objective for lakes should be 200 orgs/100mL.