WATER QUALITY AND DAIRY CATTLE PRODUCTION: SASKATCHEWAN SURVEYS

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WATER QUALITY AND DAIRY CATTLE PRODUCTION: SASKATCHEWAN SURVEYS

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ABSTRACT

The quality of water in Saskatchewan is less than ideal and poor water quality can affect livestock adversely. The sulfate content of the water can affect ruminants by interfering with Cu metabolism. Other factors such as Zn, Fe and Mo content of the feed can also have an effect on Cu metabolism. For these reasons two surveys were undertaken to investigate the source and quality of water on Saskatchewan dairy farms and the effect of this water on dairy cattle.

Survey One found that 92.8% of the 656 farms used the Holstein breed of dairy cow with an average milking herd size of 42 cows. Average milk production for Holsteins was 20.5 kg d^{-1}. Other breeds used included Brown Swiss (0.2% of farms) producing 19.2 kg $cow^{-1}d^{-1}$, mixed breed herds (4.3% of farms) producing 18.8 kg $cow^{-1}d^{-1}$, Ayrshires (1.7% of farms) producing 18.4 kg $cow^{-1}d^{-1}$, and Jerseys (1.0% of farms) producing 13.9 kg $cow^{-1}d^{-1}$. 39% of the farms surveyed used either DHAS or ROP milk recording programs.

Water quality and water sources varied throughout the province. The average well depth was 148.2 meters with 84.4% of farms using water from wells. Other sources of water included dugouts, springs, reservoirs and treated city water. The average water on Saskatchewan dairy farms contained 750.7 mg l^{-1} hardness, 595.9 mg l^{-1} sulfate, 22.8 mg l^{-1} nitrates and 1971.4 μS cm^{-1} conductivity. 76.7% of farms had water hardness levels less than 1000 mg l^{-1}. 81.8% of farms had water sulfate levels

of less than 1000 mg l^{-1}. 83.3% of farms had water nitrate levels of less than the maximum recommended level for livestock of 22 mg l^{-1}, however, 28 farms (4.2%) had nitrate levels of greater than 100 mg l^{-1}. 60.4% of farms had water conductivity levels of between 1000 and 3000 μS cm^{-1}. The levels of constituents in the water varied significantly with well depth in accordance with accepted theory on the chemical development of aquifer water. While the average water appears to be of reasonable quality there was a wide range of constituent levels that varied greatly between farms.

Stepwise regression found a small but significant negative effect of hardness on milk production ($r^2 = 0.0158$, $P < 0.01$).

In the second survey 12 farms were selected on the basis of water sulfate level, record-keeping to provide a wide range of water sulfate levels and allow accurate measurement of cow milk production and reproduction.

The average water on farms in Survey Two contained 727.6 mg l^{-1} hardness, 816.4 mg l^{-1} sulfate, 5.9 mg l^{-1} nitrates, 2313.3 μS cm^{-1} conductivity, 396.3 mg l^{-1} alkalinity, 148.2 mg l^{-1} Ca, 31.6 mg l^{-1} Mg, 320 mg l^{-1} Na and had a pH of 7.3. Farms were chosen to provide a wide range of water sulfate levels and thus water sulfate ranged from 84 mg l^{-1} to 2220 mg l^{-1}.

Average 4% FCM production in Survey Two was 31.7 kg cow-^{1}day^{-1}. Stepwise regression found that 4% FCM production was significantly affected by DMI and Days in Milk ($r^2 = 0.28$, $P < 0.01$) but not significantly affected by the intakes of protein, nitrates, sulfur, Cu, Zn and Fe. Correlation analysis indicated significant correlations between 4% FCM production and hardness, sulfates, nitrates and Ca levels in the water. Stepwise regression using 4% FCM production and water quality parameters found that nitrates had a negative effects on production (r^2 = 0.14, $P < 0.05$).

This survey indicated that cows could receive from 1.4 to 43% of their Ca requirements from Ca in the water. Cows can also receive from 5.8 to 62.8% of their daily S intake from S in the water. Na in the water can account for 6.6 to 288% of the cow's Na requirement.

Cu status, as measured by plasma Cu content, was found to be correlated to Mo intake, Days in Milk and Services per conception. There was not significant correlation between plasma Cu and Total S intake however, there was significant positive correlation between S intake and serum K, glucose, CPK, and significant negative correlation between S intake and serum urea. Total S intake was not significantly correlated to other serum parameters.

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LIST OF ABBREVIATIONS

A-G Ratio - albumin to globulin ratio
AI - artificial insemination
AP - alkaline phosphatase
AST - Aspartate aminotransferase
CPK - creatine phosphokinase
CV - coefficient of variation
d - days
DFH - days to first heat = the number of days from calving to the first observed heat.
DFS - days to first service = the number of days from calving to the first AI service.
DHAS - Dairy Herd Analysis Service (Saskatchewan)
FCM - 4% fat corrected milk calculated by using the formula:
$4\%FCM = (milk\ kg * (fat\ \% / 100) * 15) + (milk\ kg * 0.4)$
GGT - gamma glutamyltransferase
GOT - glutamic oxaloacetate transaminase
Nitrates - Unless otherwise stated refers to nitrates plus nitrites expressed as nitrate-nitrogen.
NO_3-N - nitrate nitrogen
N.S. - not significant
ROP - Record of Performance, administered under Agriculture Canada
SCC - somatic cell count
SD - standard deviation
SDHIC - Saskatchewan Dairy Herd Improvement Corporation.
SEM - standard error of the mean
TDS - total dissolved solids

1. INTRODUCTION

The effect of water quality is very important in Saskatchewan since 46% of the population depends solely or partly on groundwater. In southern Saskatchewan 71% of the communities depend solely on groundwater (SRC 1989). Until the time of my surveys the sources of dairy farm water had not been evaluated.

The quality of water on dairy farms is very important for both the animals and the equipment. High producing dairy cows require up to 100 liters of good quality drinking water daily. Equipment cleaners and soaps are less effective when water containing high total disolved solids (TDS) is used. An average sized dairy farm (40 milking cows) would require approximately 2400 l/d of water for the milking cows, another 2400 l/d for dry cows and young stock and 200-520 l/d (depending on the type of milking equipment)(Wolf and Rudnitski 1988) for milking equipment cleanup and related functions. This daily water requirement must be of suitable quality to ensure maximum milk production and cleaning efficiency.

The quality of groundwater in Saskatchewan has never been considered to be uniformly acceptable for humans consumption. Rutherford, in a 1967, study of the quality of groundwater in Saskatchewan concludes that Saskatchewan had, "little water and much salt".

Hearing of Saskatchewan's poor water quality, many livestock producers may conclude that the poor production experienced on their farms may be related to water quality. This is especially true if the family has experienced problems with the water such as bad taste, staining of fixtures, poor washing performance and crusts or scale forming on water heaters and kettles. Thus, a province-wide survey was initiated to determine the actual quality of water on Saskatchewan dairy farms and to find out if it had an effect on milk production.

2. REVIEW OF THE LITERATURE

2.0 Saskatchewan Groundwater Resources

An aquifer is a geological formation, group of formations or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Meinzer and Hard, 1925 in Price 1985). The groundwater resources of southern Saskatchewan (south of the 53rd parallel) are made up of a mixture of drift and bedrock aquifers (Henry, 1989). In southeastern Saskatchewan the aquifer types are dominated by drift aquifers (Figure 2.1) while southwest and central portions of the province contain shallow drift aquifers such that most wells produce more water when completed in underlying bedrock aquifers (Henry, 1989).

Drift aquifers refer to water deposits left by glaciers and their melt waters (Henry 1989). These aquifers tend to be high in Ca and Mg (Christiansen et al. 1965). Bedrock aquifers were laid down before glaciation (Henry 1989) and tend to be high in sodium (Christiansen et al. 1965). Saskatchewan, as well as the rest of the Canadian Prairies, have been covered several times by Continental glaciers (van der Kamp 1989). As these glaciers built-up and receded they brought to the surface sulfur-rich bedrock material (glacial drift). As this weathers, sulfate salts are produced and infiltrate the groundwater supply. The amount of sulfate found in the groundwater depends on the amount of sulfate-salts present, the path of the water movement and the

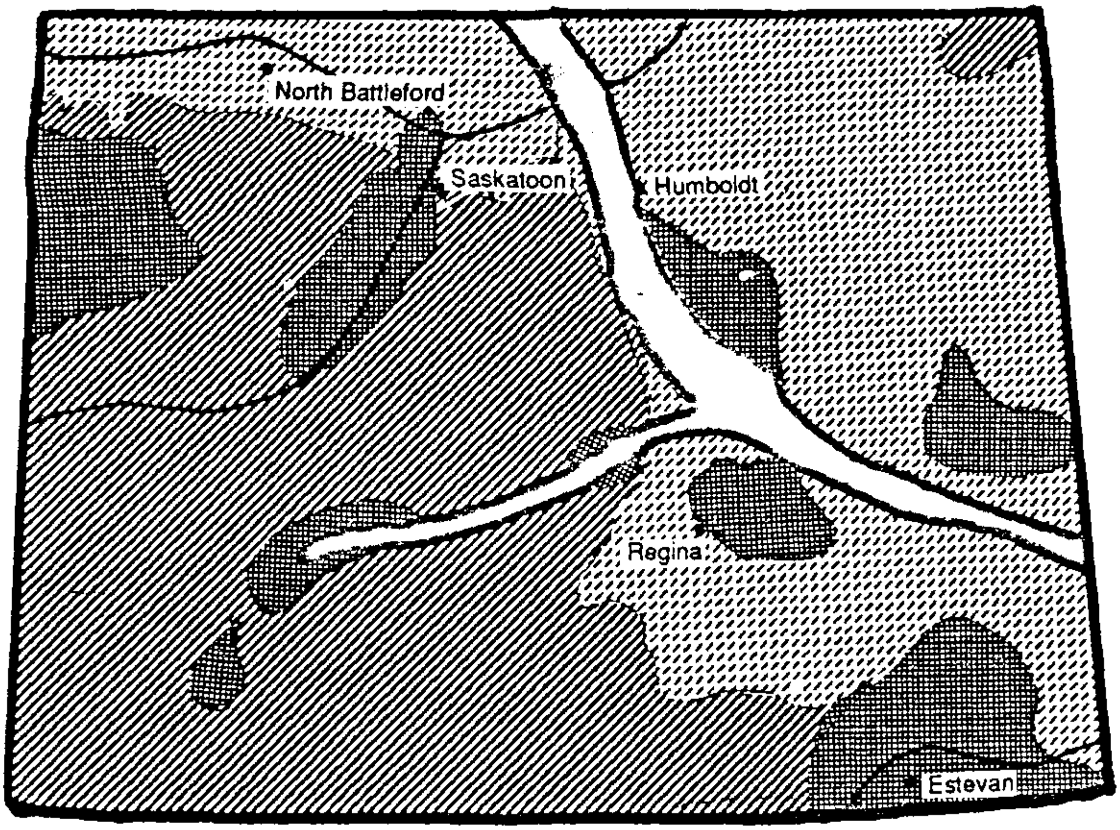


Figure 2.1: Groundwater of Southern Saskatchewan
(adapted from: Christiansen et al. 1965)

Major Aquifer Systems: include drift and bedrock aquifers which function as a hydrologic unit.

Drift and Bedrock Aquifers

Drift Aquifers

Preglacial Valleys: function as collectors of groundwater from a large area. Can be up to 91 m thick and 3.2 km wide.

Glacial Bedrock Valleys: aquifers up to 91 m thick and 19 km wide.

rate of water infiltration.

2.1 Aquifers and Water Quality

2.1.0 Introduction

Most water present in aquifers is meteoric water (water which has had contact with the atmosphere) and thus is derived from infiltration and rainfall as part of the normal hydrological cycle (Price 1985). The mineral composition of the water in the aquifer depends on many factors. These include: climate, land relief, minerals which the water contacts, the amount of time available for water and minerals to react and the action of microorganisms (ibid., Rutherford 1967).

2.1.1 The Chemical Development of Groundwater

In general, water in an aquifer moves from the area of recharge to the area of discharge (Price 1985) (Figure 2.2). Recharge areas are where the permeable material which the aquifer consists of is exposed at the surface: an outcrop. This outcrop can include mountains or hills, rivers and lakes. From there the aquifer descends underground with impermeable material below it and the water table as its uppermost point. Where the water table comes in contact with the surface a discharge area is formed. This discharge can occur as a river, lake, pond or marsh.

In areas of high rainfall, such as temperate or humid areas, water in an aquifer moves quickly from the area of recharge to

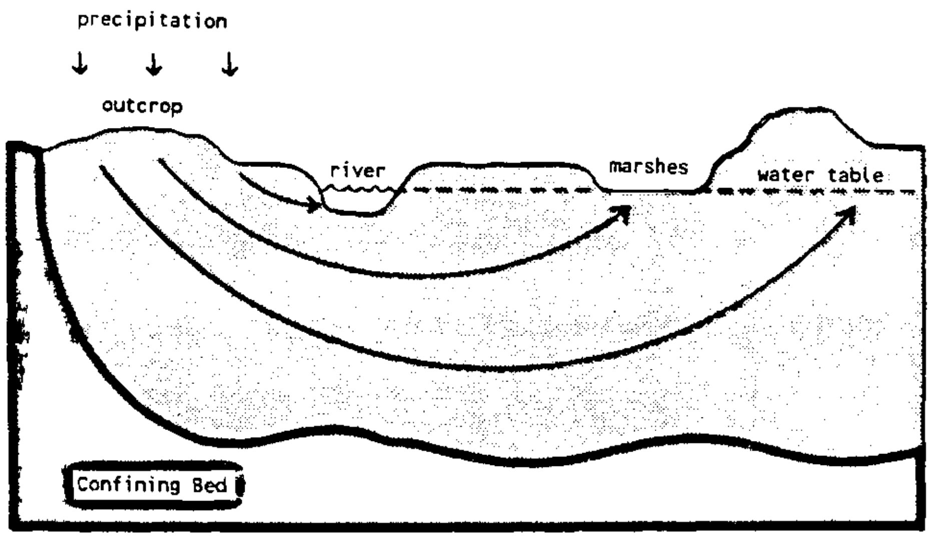


Figure 2.2: Water Flow in an Aquifer in an area of High Precipitation.
adapted from Price 1985

discharge (Figure 2.2) (Price 1985). This allows little contact time for the water to react with minerals in the porous aquifer material. Thus water from aquifers in high rainfall areas will generally not be highly mineralized.

Most of southern Saskatchewan is classified as semi-arid and thus, evaporation from soil, and transpiration from vegetation in general, exceeds average annual precipitation (Rutherford 1967). The deficit between precipitation and water consumption/losses ranges from 10 cm in the northeast to 30 cm in the drier parts of the southwest (based on 10 cm of soil storage). Thus, little recharge of groundwater occurs in a semi-arid region.

In semi-arid or arid regions water in aquifers must generally travel long distances (in some cases hundreds of miles) and go deep underground when traveling from recharge to discharge areas (Figure 2.3) (Price 1985). Water can move as quickly as one meter per day or as slowly as a few millimeters per year (Kane and Sykes 1982). This movement of water in an aquifer is important to its chemical composition and follows a predictable sequence.

Water, as precipitation, falls on the ground and moves into the soil. Oxygen dissolved in the water is partially consumed by soil organisms. Carbon dioxide in the soil atmosphere dissolves in the water and produces a weak carbonic acid solution which is capable of dissolving calcium carbonate.

In this part of the aquifer, dissolution (Figure 2.4) is

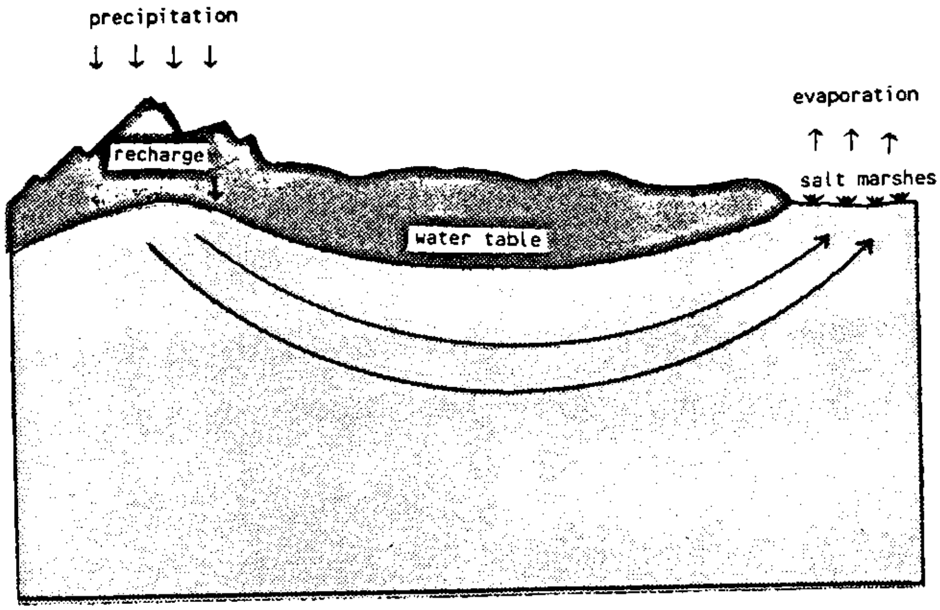


Figure 2.3: Aquifer Water Flow in a Low Rainfall (Arid or Semi-arid) Area.
adapted from Price 1985

dominant with nitrate, sulfate and bicarbonate ions present. Nitrates usually originate from nitrogen fixation by legumous plants, oxidation of organic material by bacteria or leaching from agricultural fertilizers. Sulfate ions occur due to oxidation of metallic sulfides present in many rocks by oxygen dissolved in water from the atmosphere.

At some distance from the outcrop (depending on the particular aquifer) the aquifer will dip below a confining bed of less permeable material. Dissolution still continues for some time and/or distance. With increasing distance from the recharge area dissolution becomes less and ion exchange begins to occur. Ion exchange occurs mainly on clay particles which, even though they may occur in small quantities, have a large surface area. The major ion exchange on these clay particles is the replacement of Ca and Mg ions for Na ions. Thus water in the aquifer changes from being hard (high in Ca and Mg) to soft (high in Na).

With increasing distance (and therefore usually increasing depth) from the recharge area, conditions change from oxidation to reduction. Oxygen contained in the original precipitation is used to oxidize organic material and material such as ferrous iron until all oxygen is removed. Subsequently, sulfate and nitrate are reduced. Thus as water moves deeper in the aquifer sulfate ions increase and become the major ion, then decrease (along with nitrate) as they are reduced.

The further away from the recharge area in an aquifer the smaller the amount of natural movement which will occur. This

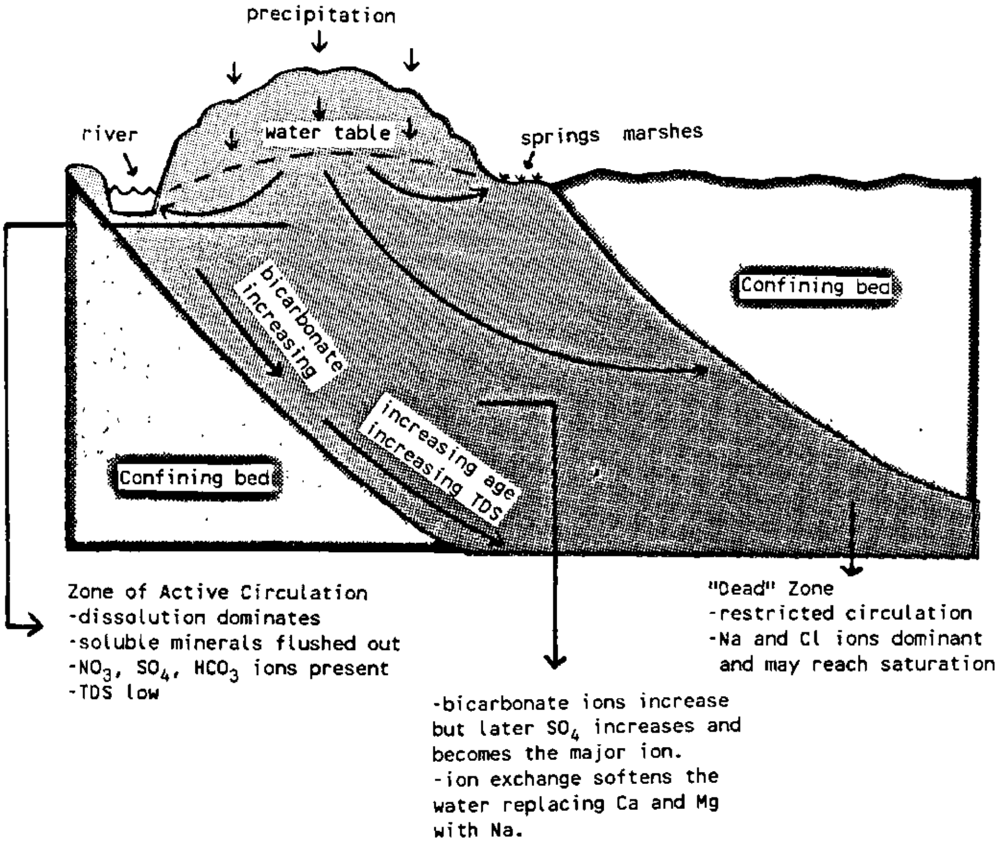


Figure 2.4: The Chemical Developement of Aquifer Water. adapted from Price 1985

allows more contact time of water with minerals and less soluble minerals will eventually become dissolved in the water.

A "dead zone" can occur a long distance or deep in an aquifer where there is very restricted circulation. Here Na and Cl are the dominant ions and may reach saturation producing a NaCl brine. If an outcrop or discharge area occurs here the result will be a salt marsh. Wells drilled into these areas will produce very saline water.

The aquifers of Saskatchewan resemble those occuring in other semi-arid regions. The recharge areas tend to be to the far north and west with the aquifers extending far south (Kane and Sykes 1982). Many discharge areas in the form of lakes, ponds and rivers occur as well as many salt marshes in the southern areas of the province.

2.2 Effects of Water Quality on Dairy Cows

2.2.0 Introduction

Poor water quality can affect an animal (Herrick 1982): by 1) altering the intake of water, feed or both, 2) producing toxic responses to substances it contains. Poor palatability may result from a specific compound such as sulfate (Weeth and Capps 1972) or from the total mineral content of the water expressed as Total Dissolved Solids (TDS) (Herrick 1982). The result of poor palatability is reduced intake of water. This can result in a reduction in feed intake and decreased production.

Toxic substances may also be present in water which may affect palatability (Herrick 1982). Those substances that have no effect on palatability have the potential to be more harmful than those that reduce palatability.

The effect of a toxic substance in water on an animal depends; whether the substance is in solution or present as a suspended solid, the chemical form, the duration and rate of intake, species and maturity of the animal, and antagonistic or the synergistic substances present in either the water or feed. The effect of a toxic substance may be sub-cellular and only express itself in increased susceptibility to disease or parasitic invasion rather than direct clinical signs (NAS 1974).

2.2.1 Factors Affecting Water Consumption by Dairy Cows

Dairy cattle require large amounts of drinking water due to their high level of milk production and corresponding high level of feed intake (Woodford et al. 1985). Many factors can influence a cow's water intake including milk production, dry matter intake (DMI), moisture content of the diet, body size, availability of water, temperature of the water, as well as environmental temperature and other factors (Little and Shaw 1978). A summary of some of the prediction equations for water intake by dairy cows is presented in Table 2.1.

Estimates of the effect of milk production on water intake of dairy cattle are based on the water content of milk (87% moisture) (Leitch and Thompson 1944). Winchester and Morris

(1956) estimated water intake for purposes other than milk production by subtracting from the total water intake 87% of the weight of milk produced by the cow. Other researchers suggest that for every kilogram of milk production the cow requires an additional 0.73 kg (Little and Shaw 1978) to 0.90 kg (Murphy et al. 1983) of water. Milk production and water intake have been

Table 2.1: Equations Predicting the Water Intake of Dairy Cattle

Andersson and Lindgren 1987

Water (l/d) = (2.97 X kg DM) + (1.11 X kg FCM) - 4.40

Murphy et al. 1983

Water (kg/d) = 15.99 + (1.58 X kg DM) + (0.90 X kg milk) + (0.05 X g Na) + (1.2 X min. Temp. °C)

Little and Shaw 1978

Water (kg/d) = (2.15 X kg DM) + (0.73 X kg milk) + 12.3

Winchester and Morris 1956

Water (gal[1]/d) = 8.7[2] + (0.29 X lb milk)

[1]imperial gallons
[2]550 kg cow consuming 7.29 kg DM/d

found to be positively correlated (r^2 = 0.29, Andersson and Lindgren 1987, r^2 = 0.58, Murphy et al. 1983), thus as milk prodution increases so does the cows water requirement.

DM and water intake have been found to be correlated in dairy cattle (Murphy et al. 1983, Little and Shaw 1978).

Regression analysis has yielded a wide range of estimates of the effect of DM intake on water intake. They include 1.58 kg water per kg of DM intake (Murphy et al. 1983), 2.15 kg water per kg of DM intake (Little and Shaw 1978), 2.97 kg water per kg of DM intake (Andersson and Lindgren 1987), and 5.44 kg water per kg of DM intake (Winchester and Morris 1956). Speculation as to the reason for the much higher estimate given by Winchester and Morris (1956) was not indicated.

In those studies where the moisture content of the feed was less than 48% (Little and Shaw 1978, Murphy et al. 1983, Andersson and Lindgren 1987) no significant effect of moisture content of the feed on water intake was found. When dairy cows are grazed they receive a significant proportion of their water from the feed thus drinking water requirements are less than for those cows on prepared feed (Castle and Watson 1973).

The effect of body size on water intake was recognized in 1956 by Winchester and Morris. Murphy et al. (1983) also recognized differences in water intake among studies, that could be due to body size differences in the cattle used. Only Winchester and Morris (1956) included body size in the calculation of water requirements. The general conclusion was that larger cows require more water.

Availability of drinking water can affect the milk production of cows on dry feed (Woodford et al. 1985). However, it may not affect cows which receive large amounts of high moisture feeds either by grazing or from silage (Castle and

Watson 1973).

Water temperature may have an effect on water intake by cows, but also depends on the environmental temperature (Woodford et al. 1985). At an environmental temperature of 15°C, less warm (24°C) water was drunk than cool (17° to 3°C) water (Andersson 1985). There were no differences in water intakes when water temperature was 3°, 10° or 17°C. At lower environmental temperatures (11°C), non-lactating cows drank less cooled water (1°C) with no effect on the digestibility of dry matter, energy or crude protein (Cunningham et al. 1964). In warm (Lofgreen et al. 1975) or tropical climates (Ittner et al. 1951) with mean environmental temperatures around 30°C beef cattle improved feed efficiency and average daily gain when water was cooled (18°C) versus uncooled water. At these high environmental temperatures the cattle require less cooled water than warm water.

The effect of environmental temperature on water intake has been noted by many researchers (Winchester and Morris (1956), Ittner et al. 1951, Murphy et al. 1983, Castle and Watson 1973, Andersson and Lindgren 1987, Little and Shaw 1978). If the water is not cooled, intake will increase with increasing environmental temperature (Winchester and Morris 1956, Ittner et al. 1951, Murphy et al. 1983). Little and Shaw (1978) found no significant change in water intake with the environmental temperature between 7° and 20°C, while over a wider range (-12.8° to 31.7°C) significant differences were observed (Murphy et al. 1983).

There are many other factors that can influence water intake by dairy cows. These include social rank, with dominant cows drinking more water (Andersson et al. 1987, Andersson and Lindgren 1987), water flow with higher flow rates increasing water intake (Andersson et al. 1984), sodium intake (50 mg additional water for each gram of Na) (Murphy et al. 1983), and breed (with British beef breeds requiring more water than European breeds) (Ittner et al. 1951).

Constituents dissolved in the water can also have an effect on the intake of water. Water containing high levels of TDS and/or sulfates and/or iron have been found to adversely affect the taste of the water for humans. In preference tests of water containing various levels of Na_2SO_4 cattle will discriminate against water containing 2,000 mg l^{-1} Na_2SO4 and reject water containing 3,000 mg l^{-1} Na_2SO_4 (Weeth and Capps 1972).

2.2.2 Effects of Sulfate in Water on Dairy Cows

Sulfate in water is the highly oxidized, stable form of sulfur that is readily soluble (McNeely et al. 1979). It can be produced by biochemical (and partly chemical), natural (IHD-WHO 1978) and bacterial oxidation of sulfides and other sulfur compounds. Other sources of sulfates in water are: from leached from sedimentary rocks, particularly gypsum, ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$), from organic materials via oxidation, industrial discharges and both wet and dry precipitation may contain sulfate from the burning of fossil fuels (McNeely et al.

1979).

The effect of high sulfate water on lactating dairy cows has not been well investigated, but, some conclusions can be drawn from beef cattle (see Table 2.2). Early work with cattle (Embry et al. 1959 in NAS 1974) found that high levels (10,000 mg l^{-1}) of Na_2SO_4 (6,986 mg SO_4 l^{-1}) added to water could lead to death of the animals. However the deaths were attributed to the total salinity of the experimental water as indicated by the Na_2SO_4 content, not the sulfate content. Short term (30 day) lower levels (3,493 mg SO_4 l^{-1}) were also experimentally not well tolerated by growing heifers (Weeth and Hunter 1971) leading to decreased water and feed consumption and lower weight gain. Lower levels (110 to 2,814 mg l^{-1} SO_4) have little effect on heifer water intake, feed intake or weight gain (Weeth and Capps 1972). One longer term (90d) study suggests that growing heifers can tolerate levels of sulfate in water up to 2,500 mg l^{-1} (Digesti and Weeth 1976). Discrepancies in maximum tolerable limits may be related to the electrolyte content of the feed (Wilson 1966) which is not stated in these experiments.

The longest term studies on the effect of high sulfate water (1,200 to 1,500 mg SO_4 l^{-1}) on cattle were a series of experiments conducted by the University of Saskatchewan (Gooneratne et al. 1987, Smart 1984, Christensen and Smart 1981, Smart et al. 1986a, Smart et al. 1986b). These experiments

Table 2.2: Effects of Sulfate in Water on Dairy Cows

Reference	Animals	SO_4 mg l^{-1}	Period days	Effects
Embry et al. 1959	heifers	6,986[1]	90	decreased water intake, weight loss, death
Weeth and Hunter 1971	heifers	3,493[1]	30	decreased water intake, 30% decrease in feed intake, weight loss
Weeth and Capps 1972	heifers	110	30	control
		1,462[1]	30	no effect
		2,814[1]	30	12% decrease in hay intake, slower weight gain
Digesti and Weeth 1976	heifers	110	90	control
		1,250[1]	90	no effect
		2,500[1]	90	no effect
Christensen and Smart 1981	steers	1,500[2]	>60	decreased weight gain
Smart 1984	heifers	1,500[2]	324	decreased liver Cu
Smart et al. 1986a	pregnant cows	42	232	control
		1,500	232	increased cow body weight, decreased calf mortality, decreased liver and plasma Cu
Smart et al. 1986b	pregnant cows	162	180	control
		1,580	180	increased cow body weight, decreased liver and plasma Cu
Gooneratne et al.1987	pregnant cows	379[3]	265	control
		1,326[3]	265	increased calf birth weight, decreased liver Cu (cow)

1As added $NaSO_4$
2Natural water containing 1500 mg SO_4 l^{-1} as well as other disolved constituants.
3Cows were provided with either 0.1% or 0.35% S in the dry matter. This was converted to the equivalent level in water assuming cows consumed 10 kg DM d^{-1} and 26.4 l d^{-1} of water (Little and Shaw 1978).

using steers, heifers, pregnant cows and their calves all found similar effects of high sulfate water (Table 2.2). The effect on growing steers (sulfate added to the ration as a substitute for high sulfate water)(Christensen and Smart 1981) was a decrease in rate of gain while the effect on growing heifers (Smart 1984) was not significant, partially due to lack of energy in the ration.

The effect of high sulfate water or its equivalent on pregnant beef cows has also been investigated (Smart et al. 1986a & b, Gooneratne et al. 1987). In all cases, cows that consumed higher levels of S either in their drinking water or in the diet, had reduced levels of Cu in the liver at parturition. These reduced levels of liver Cu (4.98 mgCu kg^{-1} DM on high S diet vs 16.23 mgCu kg^{-1} DM on low S diet) are below the normal reduction in liver Cu that occurs during pregnancy (Gooneratne et al. 1987). All the cows in this study had levels of liver Cu below the normal liver Cu levels suggested by Underwood (1981) of 100 to 400 mg kg^{-1} DM. Sulfate removal from drinking water by reverse osmosis to a level of 41.8 mgS l^{-1} had a positive effect on cow body weight (Smart et al. 1986a & b), calf birth weight (Gooneratne et al. 1987) and calf mortality (Smart et al. 1986a).

High intakes of sulfate have also been found to produce the condition polioencephalomalacia by interfering with thiamine metabolism (Raisbeck 1982, Sadler et al. 1983, Gooneratne et al. 1989, Harries 1987).

2.2.3 Effects of Saline Water on Dairy Cows

Saline water (water with high Total Dissolved Solids (TDS) content) has been recognized since the 1800's (NAS 1974) to affect cattle adversely. The salinity level in water can be measured by TDS content or indirectly by measuring the conductivity. Conductivity is usually expressed in microsiemens per centimeter ($\mu S\ cm^{-1}$) and is the ability of water to conduct electricity (IHD-WHO 1978). The conversion of conductivity measurements to TDS is dependant on the types of ions present in the water thus conductivity provides a rough estimate of TDS (IHD-WHO 1978). Conversion factors range from 1 (Water Quality Laboratory 1988) to 0.65 (McNeely et al. 1979).

Documented effects of saline water on dairy cattle began in 1913 (Larsen and Bailey 1913) who found that if slowly introduced waters containing 4,546 to 7,367 mg l^{-1} TDS had no effect on the animals. Sudden introduction of saline water to the animals resulted in reduced water intake and transient diarrhea. Two early studies found no effect on dairy milk production when the animals were consuming water containing 10,000 mg l^{-1} (Frens 1946) or 15,000 mg l^{-1} (Heller 1933) TDS. In these studies cows were producing between 8 and 20 kg of milk per day.

More recent research on the effects of saline waters on the performance of cattle has been summarized in Table 2.3. In these studies, saline water less than 12,000 mg l^{-1} TDS resulted in increased water and decreased feed consumption by growing heifers. Levels of TDS above 12,000 mg l^{-1} seem to result in

Table 2.3: Effect of Saline Water on Cattle

Reference	Animals	Water TDS	Period	Effect on Intake		Performance
				Water	Feed	
		mg l^{-1}	days			
Weeth et al.	growing	10,000	30	I[1] by 52%	-	-
1960	heifers	20,000	30	-	-	toxic
Weeth and	growing	12,500	30		control	
Haverland	heifers	15,000	30	D[2]	D	D
1961		17,500	30	D	D	D
	growing	0	30		control	
	heifers	10,000	30	I	D	D
		12,000	30	I	D	D
Weeth et al.	growing	5,000	30	I	D	D
1968	heifers	6,500	30	I	D	D
Saul and	growing	5,000	79	I	D	D
Flinn 1985	heifers	7,000	79	I	D	D
complex water		9,000	79	I	D	D
		11,000	79	I	D	D
Wegner and	heifers	250	7		control	
Schuh 1974	milking	3,500	7	D by 50%	-	-
Jaster	high	2,700	28	I	-	D
et al. 1978	producing dairy cows					
Wegner and	milking	450	600		control	
Schuh 1988	cows	4,100	600	I	-	D
		complex water				

[1]Increased intake or production.
[2]Decreased intake or production.

decreased water and feed intake. All but the very lowest levels of TDS result in reduced performance.

The effect of saline waters on high producing dairy cows has had only limited study. From the three studies outlined in Table 2.3 one may conclude that for milking cows, water containing less than 3,000 mg l^{-1} TDS from added NaCl results in increased water intake. Greater than 3,000 mg l^{-1} TDS from added NaCl results in decreased water consumption. When high TDS water is created from a mixture of salts (Wegner and Schuh 1988) these waters (containing up to 4,000 mg l^{-1} TDS) may result in increased water intake. All but the lowest levels of TDS caused reduced milk yield. One could conclude that milking cows are more sensitive to the effects of saline water than growing cattle.

2.2.4 Effects of Hardness in Water on Dairy Cows

The cations responsible for creating hard water are those of the alkali earth metals, mainly calcium and magnesium (IHD-WHO 1978). Salinity and hardness are often confused, however, they are not necessarily correlated (NAS 1974). Those saline waters which contain sodium salts rather than calcium or magnesium salts will be soft waters.

The source of the calcium and magnesium cations in nature is either the result of the interaction of dissolved carbonic acid with carbonate minerals or the product of microbial processes (IHD-WHO 1978).

Research on the effect of hardness on livestock has not been conducted (Canadian Water Quality Guidelines 1987). Suggested maximum levels of calcium in the water are listed as 1,000 mg l^{-1} with the rationale that very high calcium levels could result in phosphorus deficiency.

2.2.5 Effects of Nitrates in Water on Dairy Cows

Nitrate (NO_3) is the end product of animal and plant metabolism (Carson 1987). Sources of nitrate found in water include decaying animal or plant protein, breakdown of urea or ammonia, leaching of nitrogen (N)-fertilizers, silage juices or soils high in N-fixing bacteria (ibid., Keeney 1983). Nitrates are also found in feed especially when it is stored wet and heats up or in green feed cut after it has been stressed by frost, heat or drought (Turner 1988). Nitrate can be reduced to nitrite (NO_2) by the intestinal flora of some animals (including ruminants) and the human infant 3 or 4 months of age (Keeney 1983). Nitrates and nitrites are water soluble and readily move with ground water (Carson 1987). The level of nitrates in the water has been found to be inversely correlated with depth of well (Keller and Smith 1967).

The health effects of nitrates in water are usually due to nitrites (Keeney 1983). Nitrite, following absorption, acts as an oxidant converting the iron in hemoglobin from the ferrous state (Fe^{2+}) to the ferric state (Fe^{3+}) forming methemoglobin which has reduced oxygen carrying capacity (ibid., Carson 1987). Reported effects of high nitrates include methemoglobinemia, decreased milk production, reduced rate of gain, reproductive problems including abortions, Vitamin A deficiency, thyroid dysfunction and death (Keller and Smith 1967).

Clinical trials on nitrate poisoning in ruminants were first reported in 1939 (Bradley et al. 1939). Research on the effects of nitrate on milking cow production has been contradictory. A summary of research (Table 2.4) shows that decreased milk production has been found with nitrates (NO_3-N) as low as 1,039 mg kg^{-1} DM (Muhrer et al. 1956). Other researchers (Davison et al. 1964, Jones et al. 1966, Morris et al. 1959) found no effect on milk production at higher levels of nitrate (1,802 and 2,495 mg kg^{-1} DM).

Nitrate's effect on reproduction in cattle is also not clear. Research by Simon et al. (1959) suggests that levels as low as 1,218 mg kg^{-1} DM will cause abortions or stunted calves. Higher levels of nitrate may have little effect on reproduction (Morris et al. 1959, Davison et al. 1964). In reviewing the available literature it would seem that the effect of nitrates on pregnant animals may depend other complicating factors.

The maximum level of nitrate in drinking water recommended for humans and livestock varies with the source of the guidelines and the units used to express the guidelines (Table 2.5). These different units can all be converted the nitrate ion using the conversion factors listed in Table 2.5. In this paper "nitrates" will refer to nitrates plus nitrites expressed as nitrate-nitrogen.

Table 2.4: Effects of Nitrates on Cattle

Reference	Animals	Nitrates[12] mg kg^{-1}DM	mg d^{-1}	mg l^{-1}	Water Intake l d^{-1}	Period days	Effects
Muhrer	milking	1,733	17,330	434	39.9[3]	15	decreased milk production
et al.1956	cows	1,040	10,398	260	39.9	15	decreased milk production
Davison	milking	5,055	32,650	725	45.0[4]	63	no effect on production
et al.1964	heifers	7,555	48,975	1088	45.0	63	decreased conception rate
Jones et al.	milking	545	5,454	106	51.6[5]	63	no effect
1966	cows	2,080	20,682	402	51.6	63	decreased feed intake
Simon et al.	pregnant	1,218	11,090	265	41.8[6]	21	lesions on the placenta
1959	heifers	1,523	13,864	332	41.8	21	abortions
(stage unknown)		1,905	19,409	464	41.8	21	toxic
Morris	pregnant	1,802	25,232	1,802	14.0[7]	63	no effect on milk
et al.1959	cows	2.495	34,936	2,495	14.0	63	production, no abortions
Kahler	milking	-	220	4	50.9[8]	1050	control
et al.1975	and dry cows	-	4,326	85	50.9	1050	increased services/conception, DFS conception rate, no effect on milk yield

[1]mg NO_3-N d^{-1} calculated from mg NO_3-N kg^{-1} DM and DMI.
[2]mg NO^3-N l^{-1} = estimated equivalent level of NO_3-N in the water given the cows feed and water intake.
3Water intake not indicated. Estimated using Murphy et al. 1983 and average production of 9 kg milk d^{-1} assuming 10 kg DMI d^{-1}.
[4]Water intake not indicated. Estimated using Murphy et al. 1983 and stated average production of 19 kg milk d^{-1} and 8.1 kg DMI d^{-1}.
[5]Water intake not indicated. Estimated using Murphy et al. 1983 and stated average production of 22 kg milk d^{-1} assuming 10 kg DMI d^{-1}.
[6]Water intake based on assumptions of heifer weight = 365 kg, environmental temperature of 70°C and using equations by Winchester and Morris 1956.
[7]Cows fed fresh grass therefore low free water consumption. Assume 14 l water d^{-1} as found for grazing lactating cows in Castle and Watson 1973.
[8]Water intake not indicated. Estimated using Murhpy et al. 1983 using stated average milk production of 21.3 kg d^{-1} and assuming 10kg DMI d^{-1}.

Table 2.5: Maximum allowable levels of Nitrates

Units	Humans	Livestock	Conversion Factor[4]
NO_2	1.0[1]	10[1]	1.34
NO_3	40[2]	90[5]	1.0
$NaNO_3$	55.6[5]	138.8[5]	0.72
KNO_3	65.6[5]	163.9[5]	0.62
NO_3+NO_2	41.0[5]	100[1]	1.0
[3]NO_3+NO_2 expressed as NO_3-nitrogen	9.1[5]	22.7[5]	4.4

[1]Canadian Water Quality Guidelines 1987
[2]IHD-WHO 1978
[3]Water Quality Laboratory 1988
[4]Page,H., 1987 To convert the various units to level of nitrate ion.
[5]Calculated using the guidelines and the conversion factors

2.2.6 Effect of Water Quality on Copper Status of Dairy Cows

The only clinically and experimentally demonstrated effect of water quality on Cu status is through the sulfates contained in the water (Smart et al. 1986a). Many studies have shown lower plasma and liver Cu in cattle exposed to high sulfate water (Smart 1984, Sanders and Sanders 1983, Smart et al. 1986a, Williams et al. 1984). The effect of high sulfate water on Cu status will be discussed in more detail in section 2.3.1.2. To summarize, both inorganic and organic S compounds are reduced to sulfides in the rumen with these sulfides then binding to a variety of divalent cations especially Cu making it unavailable (Gooneratne et al. 1988). It has been shown that dietary S concentrations of greater than 0.3% will interact with Cu and contribute to Cu deficiency in Cattle (Smart et al. 1986a). Water containing 600 mgS l^{-1} as sulfate is equivalent to the total ration dry matter containing 0.4% S (Smart et al. 1986a) as compared to the requirement of 0.20% (NRC 1988).

2.3 Copper Deficiency in Ruminants

2.3.0 Simple Copper Deficiency

Hart et al. (1928) provided the first evidence that copper (Cu) had a key physiological role in that it was required for the prevention of anaemia. Simple Cu deficiency in ruminants was noted in 1937 (Bennetts and Chapman 1937). In this case enzootic ataxia was prevented by the administration of Cu.

Cu deficiency can clinically manifest itself in many ways due to the variety of enzymes in which Cu is a part (O'Dell 1976). As seen in Table 2.6 cuproenzymes are found throughout the body, are mostly oxidases and function in systems ranging from energy transfer (cytochrome c oxidase) to melanin formation (tyrosinase). Relating deficiency of Cu to clinical symptoms Table 2.7 indicates the known enzymes involved in the recognized pathology of Cu deficiency.

Table 2.6: Cuproenzymes Found in Vertebrate Tissues

Enzyme	Source
Cytochrome c oxidase	Mitochondria
Superoxide dismutase,Hemocuprein	Erythrocytes and heart
Ceruloplasmin	Plasma
Tyrosinase	Melanomas and skin
Uricase	Liver and kidney
Dopamine b-hydroxylase	Adrenal gland
Lysyl oxidase	Aorta and cartilage
Spermine oxidase	Bovine plasma
Diamine oxidase, Histaminase	Kidney
Tryptophan-2,3-dioxygenase	Liver

Adapted from: O'Dell, 1976

Table 2.7: Metabolic Disorders Resulting from Copper Deficiency*

Pathology	Metabolic Effect	Enzyme Involved
Achromotrichia	Melanin formation	Cu-containing polyphenyl oxidases eg. tyrosinase
Cardiovascular lesions	Crosslink formation in elastin	Amine oxidase
Bone changes	Crosslink formation in collagen	Lysyl oxidase
Central nervous system disorders (Neonatal ataxia)	Myelin aplasia via lack of energy or catecholamine deficiency.	Cytochrome oxidase and /or amine oxidase
Anemia	Iron (Fe) deficiency via lack of transport from intestine.	Ceruloplasmin
Change in wool or hair (Steely wool)	Keratinization	Unknown
Scouring		Unknown
Infertility or poor fertility		Unknown
General Unthriftyness		Unknown

*Adapted from: O'Dell, 1976

2.3.1 Conditioned Copper Deficiency

2.3.1.0 Introduction

Cu deficiency can be enhanced (conditioned) by the presence of other compounds in an animals diet (Humphries et al. 1983). The most significant and well studied of these compounds are molybdenum (Mo) and sulfur (S). Other interacting compounds that may be important are zinc (Zn) and iron (Fe).

2.3.1.1 Differences in Copper Metabolism Between Cattle and Sheep

When discussing Cu in animals some mention should be made on the variability in metabolism found between different species, especially cattle and sheep. Underwood (1981) found the following differences in the manifestations of Cu deficiency: lambs can suffer from neonatal ataxia while calves generally do not, cattle can develop cardiovascular lesions while sheep do not and cattle can develop scours when exposed to low Cu diets while sheep do not. Some Cu deficiency effects that cattle and sheep do share are achromotrichia, defects in keratinization and changes in fertility.

Cu toxicity also occurs more readily in sheep than in cattle (Underwood 1981). This may be due to a mechanism in sheep which protects them from excessive loss of Cu via biliary excretion (Gooneratne et al. 1989). The major route of Cu excretion from mammals is via the bile (Evans 1973). It is postulated that since sheep are not able to excrete Cu via the bile as quickly as other species they accumulate Cu in the liver more quickly and thus more easily develope Cu toxosis (Gooneratne et al. 1989).

2.3.1.2 Copper and Sulfur Interactions

The production of sulfide in the rumen plays a key role in the interaction of Cu and S. Using mixed populations of rumen bacteria, Hendrickx (1961) found that S in the form of sulfate, sulfite or sulfide were all used in the synthesis of S-amino acids (S-A.A.). The steps in the formation of S-A.A. are as follows:

$$SO_4^{2-} \longrightarrow SO_3^{2-} \longrightarrow S^{2-} \longrightarrow \text{S-A.A.}$$

Bray (1969b) states that there are three avenues from which sulfide is lost from the rumen: passage across the rumen wall, passage down the alimentary tract and oxidation of the sulfide ion. Absorption across the rumen epithelium has proven to be the main factor responsible for loss of sulfide from the rumen (Anderson 1956, Bray 1969b). This sulfide is then oxidized to sulfate in the liver and is either utilized by body tissues or excreted by the kidney (Huisingh et al. 1973). If sulfide does pass down the alimentary tract it is rapidly absorbed in the duodenum with virtually none appearing in the feces (Bray 1969b). Excess sulfide that is absorbed from the intestine is also excreted via the kidney (Bray 1969a). In periods of low S intake any excess S is recycled back to the rumen in the form of sulfate via the bloodstream (Anderson 1956, Bray 1969c).

Animal studies of Cu - sulfate interactions have shown that added sulfate can decrease Cu storage in sheep (Dick 1954, Wynne et al. 1956). Suttle and McLaughlin (1976) demonstrated that dietary S exerts a predominant and independent effect on Cu availability in sheep when compared to the effects of Mo on Cu availability. The mechanism of their interaction is not known but Huisingh et al. (1973) postulated it to be as in Figure 2.5.

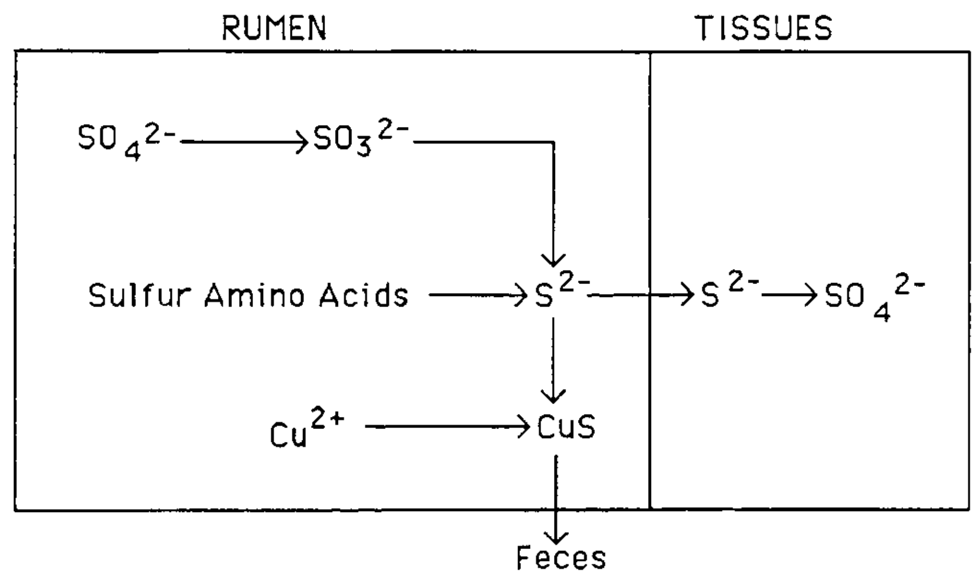


Figure 2.5 - A model for the interaction of copper and sulfur in ruminants (Huisingh et al. 1973).

Support for this theory came from Mills (1960) who showed that the presence of high levels of sulfide in the rumen decreased the concentration of soluble Cu through the formation of unabsorbable cupric sulfide (CuS). Halverson et al. (in Huisingh et al. 1973) proposed that CuS can form in tissue and blood.

Suttle and Peter (1985) propose that this CuS compound forms in the abomasum and that the differences in Cu availability of different feeds are associated with different rates of flow of Cu and sulfide into the abomasum. They found that Cu is primarily associated with the solid phase of the rumen and thus flows slowly to the abomasum. Since sulfide is associated with the liquid phase of the rumen it would flow more quickly to the abomasum than the Cu associated with the solid phase. The Cu associated with the particulate matter would avoid the early peak of sulfide flow to the abomasum and reduce the amount of potential CuS compound formed. Another possible mechanism mentioned is that at the lower rumen pH associated with carbohydrate-rich diets the formation of H_2S rather that HS^- ions is favored (Bray and Till 1975). This may favor absorption of sulfide from the rumen rather than flow to the abomasum thus decreasing the potential for CuS formation.

2.3.1.3 Copper and Molybdenum Interactions

Antagonism between Mo and Cu was first discovered in 1943 (Ferguson et al. 1943) when cattle on pastures containing above normal levels of Mo developed signs of Cu deficiency. The effect of Mo on Cu storage in sheep was known as early as 1945 (Dick and Bull 1945); the mechanism for the interaction was unknown. Davis (1950) in reviewing the then recent studies on Cu-Mo antagonism could only conclude that "Mo added to the ration of cattle results in a lower storage of Cu only when the total Cu intake is just adequate or slightly above adequate for the animals requirements". A suspect factor in the Cu-Mo antagonism picture was elucidated by Dick (1952) as being something in alfalfa hay. This factor was later found to be sulfate (Dick 1953). Using X-ray diffraction techniques Dowdy et al. (1969) found that the complex was similar to the mineral Lindgrenite: $2CuMoO_4 \cdot Cu(OH)_2$. The Cu-Mo complex was also found to precipitate at or near neutral pH with a molar composition of 4:3 (Cu:Mo) (Dowdy and Matrone 1968a, Matrone 1970); thus optimal conditions exist in the rumen for its formation. Matrone (1970) however, found that this complex broke down at pH of 3 or lower so one would think that the Cu would become available again after passage through the abomasum or perhaps reform in the Cu-Mo complex in the duodenum.

An overall model of Cu-Mo interaction in ruminants was proposed by Huisingh et al. (1973) and shown in Figure 2.6.

This model proposed that Cu becomes unavailable in the rumen through the formation of cupric molybdate which is absorbed, transported and excreted as a unit. The complex also results in both Cu and Mo being less available. The alleged unavailability of this complex is supported by the work of Dowdy and Matrone (1968b) who injected sheep with the complex and found that is was not available for ceruloplasmin synthesis. The model further shows that under conditions where no complex is formed prior to absorption the complex may form at the tissue level. Theoretical evidence for this was put forward by Suttle (1974) who postulated that at low Mo levels the primary site of interaction is in the

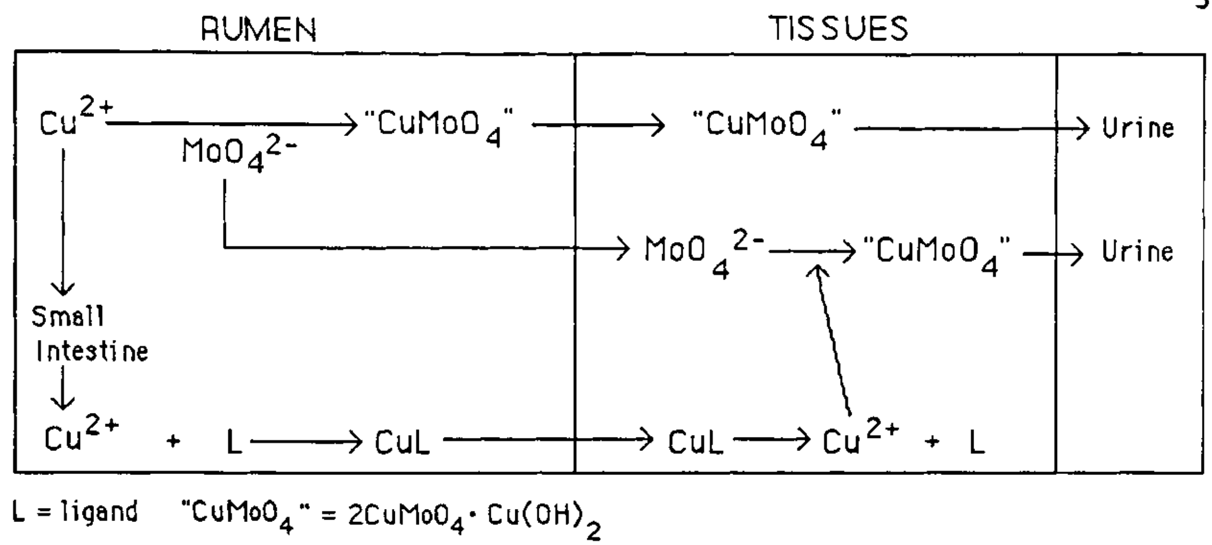


Figure 2.6 - A model for the interaction of copper and molybdenum in ruminants (Huisingh et al. 1973).

gut where Mo decreases Cu absorption. High dietary Mo concentrations lead to high blood Mo levels which favor the formation of Cu-Mo complexes and accumulation of unavailable Cu in the tissue. This theory was later proven true by Mills (1980) who characterized levels at which the different interactions occurred. Mills (1980) found that at dietary Mo levels of 1 to 10 mg kg^{-1} DM there was a marked decrease in the efficiency of Cu absorption. With dietary Mo levels >10 mg kg^{-1} DM Cu absorption remained reduced and systemic defects in its metabolism also developed. These systemic effects include redistribution of Cu between plasma proteins with a decrease in the enzyme activity and Cu content of ceruloplasmin. This is accompanied by an increase in the Cu and Mo content of the albumin fraction of the blood.

Suttle (1974) opposed the significance of the Cu-Mo complex formed in the rumen because it was known to dissociate at abomasal pH. He did, however, propose that Mo has a true systemic effect on Cu by impairing uptake of Cu by tissues or by decreasing the capacity of plasma proteins to bind Cu. Thus it was concluded (Suttle and McLaughlin 1976) that Mo has a lesser and S-dependant effect on Cu availability in the ruminant. Mo was still found to alter Cu metabolism on its own (Humphries et al. 1983, Phillippo and Humphries 1987) and may also related to iron metabolism. From about 1980 on the concern of Cu nutrition centered around the formation and metabolism of a Cu-Mo-S complex (Clarke and Laurie 1980, Suttle 1983, Humphries et al. 1983).

2.3.1.4 Copper, Molybdenum and Sulfur Interactions

The first recognition of a Cu-Mo-S interaction and formation of thiomolybdates is attributed to Berzelius (in Mellor 1931). He found that the 'sulfomolybdates' (thiomolybdates) (R_2MoS_4) formed when excess hydrogen sulfide was passed through a neutral or alkaline solution of molybdates. These thiomolybdates were also shown to form very insoluble Cu salts though the salts themselves were not characterized. Thiomolybdates themselves have been defined as "a series of compounds formed by the progressive substitution for S and oxygen in the $MoO_4{}^{2-}$ anion when HS_2 and $MoO_4{}^{2-}$ interact <u>in vitro</u> at neutral pH" (Suttle and Field 1983). This is shown in Figure 2.7.

$$MoO_4{}^{2-} \longrightarrow MoO_3S^{2-} \longrightarrow MoO_2S_2{}^{2-} \longrightarrow MoOS_3{}^{2-} \longrightarrow MoS_4{}^{2-}$$

Figure 2.7 - The formation of Thiomolybdates.
(Mills 1980)

The mechanism of Cu-Mo-S interaction in ruminants was first proposed by Dick (1956) to be that of sulfate blocking the transport of molybdate across membranes with Cu transport being impaired in the process. Until 1970 some work continued on the three-way interaction but most focused on the interactions between Cu and Mo (Dowdy and Matrone 1968), Cu and S (Wynne and McClymont 1956), and Mo and S (Dick 1956). The three-way interaction between Cu, Mo and S could be summarized as by Huisingh et al. (1973) in Figure 2.8.

Cu in the diet can become unavailable by two routes: 1) through the interaction with Mo to become cupric molybdate which is absorbed, transported and excreted as a unit with both Mo and Cu being less biologically available or 2) by the formation of insoluble cupric sulfide in the rumen, intestine or tissue. Therefore Mo or sulfate can either increase or decrease the severity of Cu deficiency in ruminants depending on the Cu status of the animal and the dietary levels of sulfate or Mo (respectively).

In 1970 Matrone put forward a hypothesis that characterized the three-way interaction. He had found that when aqueous solutions of sodium molybdate and Cu sulfate were mixed a precipitate was formed. Assuming this was the precipitate of a three-way interaction Matrone analyzed it for Cu, Mo and sulfate. No sulfate was found by either his or an independent laboratory (this confirmed earlier work by Dowdy and Matrone 1968a and b) however no mention of the S content of the precipitate was made. He then assumed that the form of sulfate involved in the

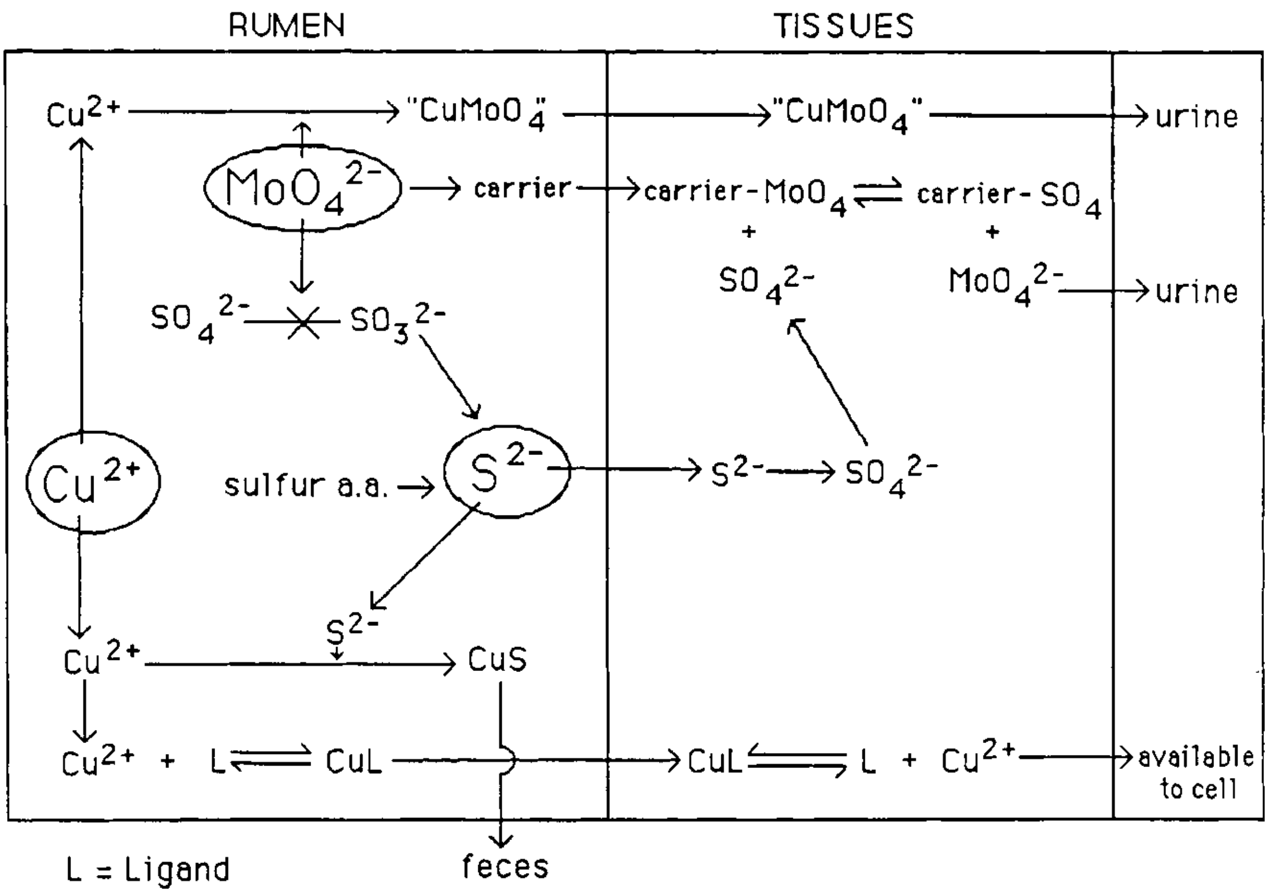


Figure 2.8 - A model for the interaction of copper, molybdenum and sulfur in ruminants (Huisingh et al. 1973).

interaction was "not sulfate per se but an intermediate (X) in the bioreduction of sulfate to sulfide which occurs in the rumen". In the rumen this three-way interaction produced the triple unabsorbable complex 'Cu/Mo/X'. To explain the different results obtained with different concentrations of Mo Matrone (1970) went on to hypothesize that at low levels of Mo (too low to inhibit sulfate reduction) X is formed and the formation of 'Cu/Mo/X' is maximized. At high levels of Mo sulfate reduction is inhibited and less X and thus less 'Cu/Mo/X' is formed. Suttle (1974) believed this 'X' to be sulfide because of the chemical reaction known to occur in vitro where sulfide and molybdate combine to form MoS_4^{2-} which also occurred in the rumen. The MoS_4^{2-} would them combine with Cu to form the unabsorbable $CuMoS_4$. Dick et al. (1975) also postulated the formation of these same insoluble copper-thiomolybdates in the rumen.

Validation of the thiomolybdate-Cu interaction hypotheses, rests on the indirect evidence that ruminants respond to preformed thiomolybdates in much the same way as they do to dietary molybdate plus sulfate (Suttle 1980). Suttle (1980) goes on to conclude that thiomolybdates probably do form at an early stage of the MoO_4^{2-} and SO_4^{2-} interaction in the rumen but the effects on Cu metabolism probably involve a compound more complex than the molybdate ion. This is supported by the work of Clarke and Laurie (1980) who found that under physiological conditions in the rumen di- and trithiomolybdates form more readily than tetrathiomolybdates. They also found no specific reactivity of the tetrathiomolybdate ion towards Cu.

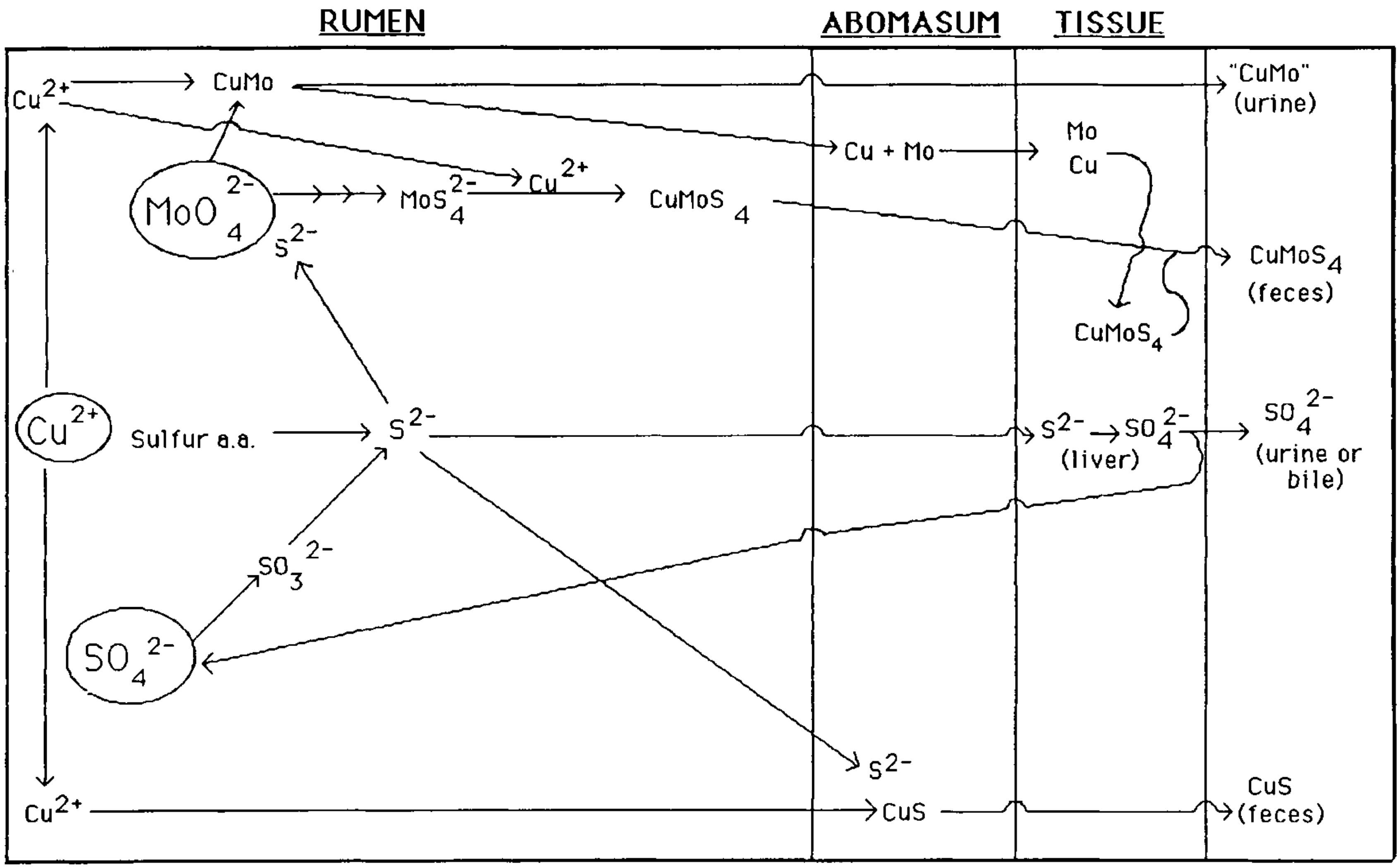
Suttle and Field (1983) also had criticisms of the thiomolybdate hypothesis. Their criticisms were: 1) that di- and trithiomolybdates form more readily in the rumen than tetrathiomolybdates and only the tetra- form is known to impair Cu absorption in the rat. 2) Extensive accumulation of TCA-insoluble Cu in plasma which characterizes the response of rats to MoS_4 is not seen in ruminants at equivalent intakes of Mo. 3) Instability of thiomolybdates at low pH suggest degradation in the abomasum (Clarke and Laurie 1980).

Based on this information and that obtained in their experiment Gawthorne et al. (1985) concluded that Mo compounds in the presence of sulfide are converted to thiomolybdates in the rumen. These thiomolybdates react rapidly with particulate matter and proteins to form complexes that bind Cu strongly. If this particulate matter and proteins are poorly digested then the Cu and thiomolybdates associated with them would be less available in the lower digestive tract.

2.3.1.5 Summary of Copper, Molybdenum and Sulfur Interactions

A summary of the interactions of Cu, Mo and S is illustrated in Figure 2.9 and also discussed in the conclusion of this section. In the ruminant Cu, Mo and SO_4 in their various forms are ingested and passed to the rumen. Here some SO_4 (and S-A.A.) are reduced to sulfide which is either recirculated via the

Figure 2.9: Cu, Mo and S Interactions in the Ruminant



adapted from: Huisingh et al. 1973

liver and bile if the S status of the animal is low or the sulfide combines with Cu^{2+} to produce insoluble CuS or combines with $MoO_4{}^{2-}$ and Cu^{2+} to produce insoluble Cu-containing compounds.

Cu^{2+} and Mo will also complex in the rumen. The resulting CuMo compounds can be absorbed through the rumen wall and excreted via the kidney. If this compound is not absorbed it will be transported, with other food particles, to the abomasum where it may breakdown under the low pH at that site. The freed Cu and Mo may then be absorbed or recombine in the lower intestine. In the tissue free Cu, Mo and S may form biologically unavailable Cu-thiomolybdenate compounds.

2.3.1.6 Copper and Zinc Interactions

Interaction between Cu and Zinc (Zn) was first recognized by Smith and Larson (1946) who found that supplying supplemental Cu would alleviate some symptoms of zinc toxicity in rats. The reverse is also true, that some symptoms of Cu toxicity can be alleviated with Zn supplementation (Ritchie et al. 1963). Work on the exact nature of the interaction has been carried out on monogastric systems (VanReen 1953, Ritchie et al. 1963 and Suttle and Mills 1966) leading to the theory that the site for the antagonism be in or on the intestinal epithelium (VanCampen 1967) as illustrated in Figure 2.10 by Mills (1980). Normally Cu is not retained in the enterocyte of the villus. However, when there are high concentrations of Zn in the intestinal lumen Cu is

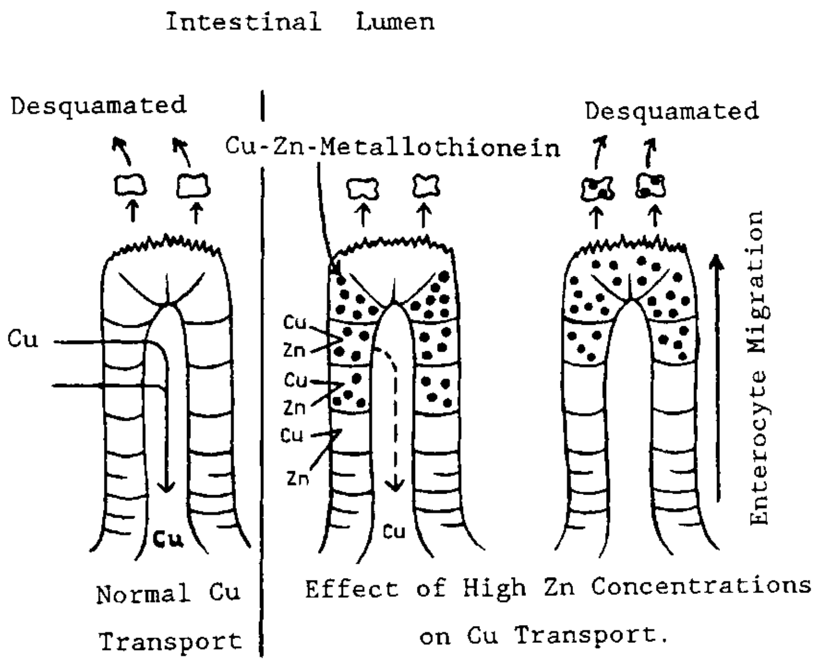


Figure 2.10: Copper and Zinc Antagonism in the Intestine.

High levels of Zn result in Cu-Zn-metallothionein synthesis which is mostly retained in the enterocyte until it is desquamated into the lumen of the intestine.
adapted from: Mills, 1980.

retained in the enterocyte along with Zn and forms Cu-Zn-Metallothionein. Since the metallothionein and the enterocyte containing the metallothionein is desquamated less Cu is thus unavailable to the animal (Mills 1980).

Work with ruminants (Towers et al. 1981 and Mills et al. 1967) shows that Cu - Zn antagonism can also occur in these animals though it is not known if the site for the antagonism in the same as in monogastrics. It is suggested (Chvapil et al. in Mills 1974) that excess Cu increases the fragility of lysosomal membranes, an effect that is reversible by Zn.

While most studies are concerned with toxicity of Cu or Zn and the helpful effects of the other element it is noted that quantities of Cu or Zn many time the requirement are generally required to produce a toxic response. Thus, when animals are receiving a diet deficient in one of the elements much less antagonistic ion is required to produce an effect (VanCampen 1970).

Mo can reduce the absorption and S decrease the solubility of Zn in the intestine (Golfman and Boila 1988). Thus levels of these elements in the ration must also be noted.

2.3.1.7 Copper and Iron Interactions

The antagonism between Cu and Fe was initially noted by Coup and Campbell in 1964 when high Fe water was used to irrigate pasture-land. The cows on this pasture began exhibiting symptoms of Cu deficiency and thus a trial was initiated to determine the effects of high dietary Fe content on cows. One noted response of the trial was low blood or plasma Cu in treated animals. This phenomenon , as well as reduction in liver Cu, was also reported by other researchers (Binot et al. 1969, Campbell et al. 1974, Humphries et al. 1983).

The nature of the antagonism between Cu and Fe is still not fully understood (Humphries et al. 1983). Speculation is that Fe stimulates the production of sulfide in the rumen which in turn combines with Cu making it unavailable (Suttle et al. 1984). Other information notes that the change in Cu status resulting from high Fe levels does not produce the same clinical reactions as reduction in Cu status caused by high dietary Mo (Humphries et al. 1983). For example, low Cu status resulting from high Mo intake will cause delay in estrus while low Cu status caused by high Fe intake had no effect on fertility (Phillippo et al. 1987).

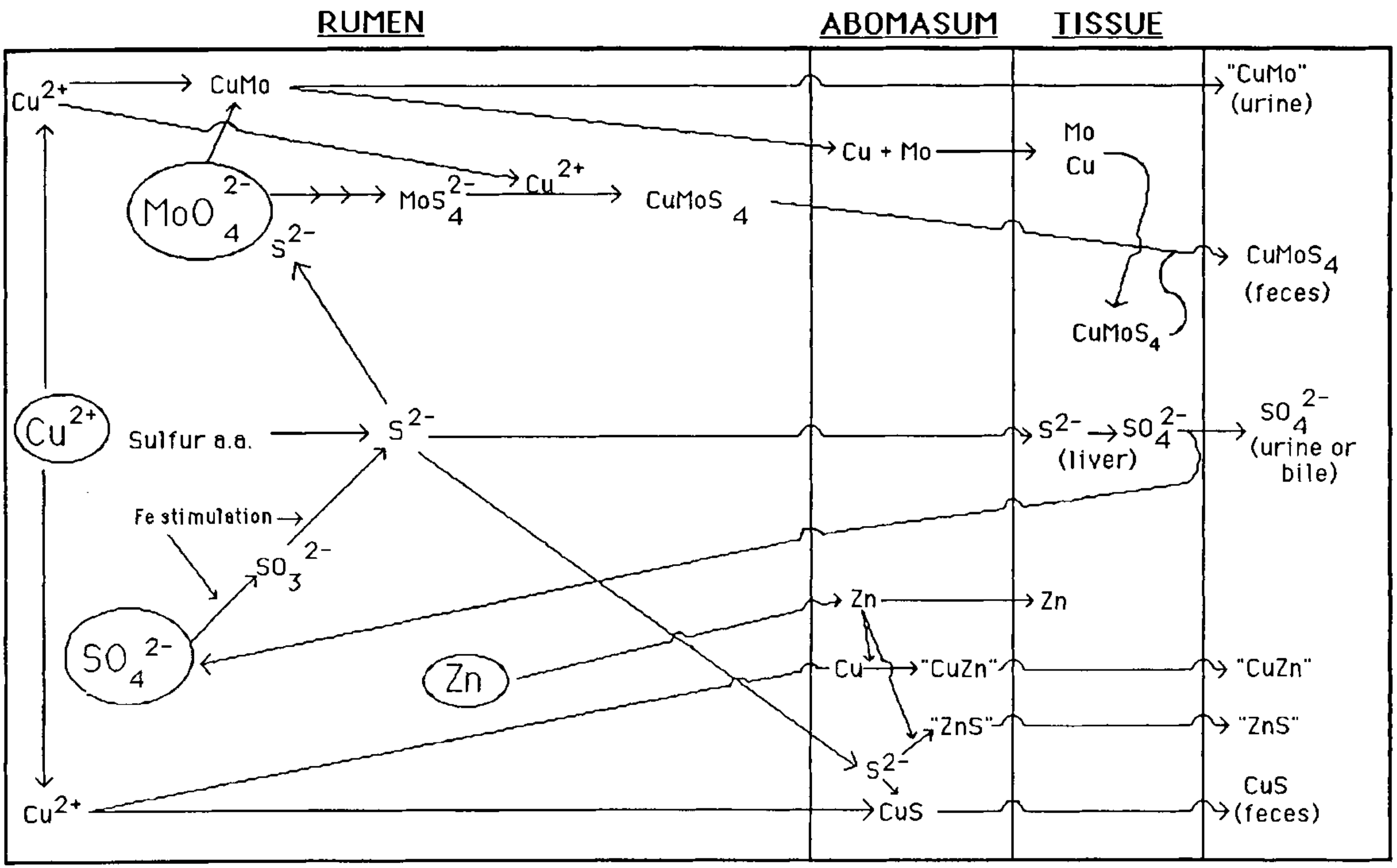
A link between Cu deficiency anemia and Fe has been put forward by Frieden (1971). His theory was that Cu deficiency results in less plasma ceruloplasmin. Since one of the functions of ceruloplasmin is to control the rate of uptake of Fe from the intestine via transferrin then less Fe is transported and Fe-deficiency anemia develops when Cu intake is inadequate.

2.3.1.8 Summary of Cu, Mo, S, Zn and Fe Interactions.

Interactions between Cu, Mo, sulfate, zinc and iron are very complex in the ruminant animal. While it is known that these five compounds interfere with the absorption and utilization of each other the mechanisms for these actions are not well understood. Current knowledge of the interactions between these five compounds can be summarized in Figure 2.11 Cu, Mo, sulfate, zinc and iron are ingested and pass to the rumen. Here the sulfate is reduced to sulfide by rumen organisms (possibly stimulated by the presence of iron) and then either combine with Mo to produce thiomolybdates, pass down to the abomasum and complex with Cu, pass down to the lower intestine and either be absorbed or interact with zinc or be absorbed through the rumen wall. The thiomolybdate compounds may then bind to particulate matter, proteins and Cu and may be not as digestible in the lower digestive tract. The CuS complex formed in the abomasum is not absorbed and is thus excreted in the feces. The sulfide absorbed through either the rumen wall or the lower digestive tract is oxidized to sulfate in the liver. If the S status of the ruminant is low this sulfate will be recycled back to the rumen. Excess sulfate is excreted in the urine or via the bile.

Cu and Mo can also complex in the rumen. This complex can be absorbed through the rumen wall but neither the Cu or the Mo is as biologically available in this form and the complex is excreted by the kidney. The CuMo complex that is passed out of the rumen is dissociated at the pH of the abomasum and may becomes available in the lower digestive tract and be absorbed. In the tissue free Cu, Mo and S can combine to form Cu-thiomolybdenate compounds that are biologically unavailable and

Figure 2.11: Cu, Mo, S, Zn and Fe Interactions in the Ruminant



adapted from Huisingh et al.1973

excreted via the urine and bile.

Free Cu in the intestine can also complex with zinc if the absorbability of zinc is not compromised by S or Mo. If prior deficiency of Cu has reduced the production of ceruloplasmin then less iron will be transported to the tissues.

The result of all of these possible interactions is that less Cu is available to the animal and signs of Cu deficiency may develop.

3.0 RESEARCH

3.1 Objectives

Survey One

1. Provide Saskatchewan dairy farmers with information about the water quality on their farms.
2. Estimate the effect of water quality on milk production of dairy cows in Saskatchewan.
3. Provide provincial and regional summaries of water quality.

Survey Two

Provide recommendations as to the effect of water quality parameters on the milk production and reproduction of dairy cows.

This will be accomplished by:

1. Observing the differences in production and reproduction on dairy farms with a range of sulfate levels in the water.
2. Observing the effect of different levels of total S intake from feed and water on plasma Cu and Zn of the dairy cows.
3. Observing the effect of Cu and Zn intake from the feed on plasma Cu and Zn (respectively).
4. Observing the effect of water quality parameters other than sulfate content on production and reproduction in dairy cows.

4. SURVEY ONE

4.0 Materials and Methods

This Saskatchewan-wide survey was conducted in January and February of 1987 and obtained data from all the 720 dairy farms in Saskatchewan. Water sample jars and accompanying questionnaires were distributed via milk trucks courtesy of Dairy Producers Cooperative Ltd. Organization and instruction of milk-truck drivers was conducted by Connie Yuzak who also collected the data and prepared the resulting data for computer entry. Distributing the jars and questionnaires by milk truck allowed the collection of data from all dairies shipping milk in Saskatchewan. Producers were instructed to obtain the water sample from the water source which the cows consumed as it is often different than the water used for other purposes in the barn.

The water samples were sent to the Water Quality Laboratory in Regina and tested for total hardness, sulfates, nitrates (nitrates plus nitrites expressed as nitrate-nitrogen) and conductivity using procedures outlined in Table 4.1. Survey questions included the producer's name, address, land location, type of water supply, well depth and type, number of milking cows, number of dry cows, type of milk recording program used, bulk tank amount of milk (kg) for this shipment and the number of times the cows were milked since the last milk pickup (Appendix A). Due to confusion on the first questionnaire the second one (approximately one month later) was re-worded to clarify the number of times per day the cows were milked (Appendix A). Milk production per cow per day was calculated using the formula:

$$\text{Milk per cow per day} = \frac{\text{kg milk shipped}}{((\text{number of milkings}/2)/\text{reported number of cows milking})}$$

Table 4.1: Water Testing Procedures

Parameter	Method	Reference
Hardness	EDTA color indicator	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
Sulfate	Automated Methlythymol Blue	Analytical Methods Manual, Environment Canada - Inland Waters Directorate 1979
Nitrates	Conversion of nitrate to nitrite to nitrous acid then diazotization.	Water Quality Laboratory, 1988
Conductivity	YSI model 35 conductance meter	Water Quality Laboratory, 1988

Statistics

Data was analyzed using SAS (Statistical Analysis System, production version 5.16). The mean of the two samples taken on each farm was then used in further analysis of the data. This included overall means and frequencies of the parameters.

The effect of water quality on milk production was tested using the stepwise regression of SAS STEPWISE. The effect of well depth on water quality parameters was tested using the GLM (General Linear Model) to do an ANOVA (Analysis of Variance) and Scheffe's test to achieve mean separation.

4.1 Results and Discussion

No significant differences were found between samples one and two using the General Linear Models (GLM) procedure in SAS (Statistical Analysis System). Thus, the mean of each parameter (from each farm) was used in further analysis.

4.1.0 Average Saskatchewan Farm Description

4.1.0.0 Farm Description

The breeds used for milk production is Saskatchewan are dominated by Holsteins which are the only breed on 92.8% (Table 4.2) of the farms. Herds using a mixture of breeds were the next most frequent at 4.3% of all farms. Ayrshires, Jerseys and the Brown Swiss breeds were found on 1.7%, 1.0% and 0.2% of Saskatchewan dairy farms respectively.

Table 4.2: Farm Description

Breed Type	Number of Farms(%)	Mean Milking Herd Size	Mean Milk Production (kg $cow^{-1}d^{-1}$)
Holstein	609 (92.8%)	42.2	20.5
Ayrshire	11 (1.7%)	27.3	18.4
Jersey	7 (1.0%)	33.4	13.9
Brown Swiss	1 (0.2%)	18.0	19.2
Mixed Herds	28 (4.3%)	42.4	18.8
Total	656 (100%)	-	-
Average	-	42.0	-

Milking herd size appeared to vary with the type of breed. However, there were no significant differences between breeds. The largest herds appeared to be either Holstein (42.2 cows) or mixed breed herds (42.4 cow).

As expected, Holsteins had significantly higher milk production (20.5 kg d^{-1}) than other breeds (Table 4.2). This was slightly lower than the February 1987 DHAS average for Holsteins of 21.1 kg 4%FCM. However, the fat content of the milk during the survey was not determined.

Milk production of the other breeds in the survey were similar to known breed averages (Cole and Garret 1974). In order of decreasing daily milk production the breeds can be listed as: Holstein, Brown Swiss, Ayrshire, and Jersey.

4.1.0.1 Water Sources

Saskatchewan dairy farms relied mainly on wells for their source of water with 84.4% of dairy farms using wells (Table 4.3). Dugouts were used by 13.1% of dairy farms with other sources of water being used by 2.5% of dairy farms.

Table 4.3: Water Sources

Source	Number of Farms	Percentage Use
Well	554	84.4%
Dugout	86	13.1%
City Water[1]	10	1.4%
Lake Reservoir	3	0.5%
Spring	4	0.6%

[1]Water obtained from the nearest population center.

4.1.0.2 Performance Program Use

The two types of recognized milk recording programs available to Saskatchewan dairy farms are Dairy Herd Analysis Service (DHAS) and Record of Performance (ROP). The ROP program is only for purebred cattle and produces official production records for those cattle. DHAS is for purebred or grade dairy cows and provides more management information. At the time of the survey 36.9% of farms used DHAS and 13.7% of farms ROP (Table 4.4). Thus 50.6% of dairy farms were on one of the recognized milk recording program.

Table 4.4: Performance Program Use

Program Type	Number of Farms	Percentage Use
DHAS	242	36.8%
ROP	90	13.7%
No Program[1]	324	49.4%

[1]Herds not using DHAS or ROP.

Since the time of the survey the two recognized milk recording programs, DHAS and ROP, have been merged. All herds on these programs have now been offered the use of SDHIC (Saskatchewan Dairy Herd Improvement Corporation).

4.1.1 Well Depth and Water Quality

4.1.1.0 Introduction

Average water quality from the 554 farms using water from wells is summarized in Table 4.5. If increased in well depth is assumed to correspond to increased depth of the associated aquifer then the quality of water found at different well depths conforms to known theory of water quality in aquifers (Price 1985) as discussed previously in section 2.1.1.

The assumption of well depth corresponding to aquifer depth may not be correct since the question of well depth put forth to producers did not define what was meant by the term "well depth". Thus well depth could be the depth of the hole drilled or dug or the depth of the water within the well. Also, estimation of well depths are usually provided by the well digger or driller which may result in a biased estimate.

4.1.1.1 Hardness

As well depth increased hardness increased and then gradually decreased as shown in Figure 4.1. This is consistent with Price (1985) who states that with increasing depth in an aquifer Ca and Mg ions in solution are exchanged for Na ions on clay minerals. Thus, as the aquifer deepens the water changes from hard to soft.

Table 4.5: Well Depth and Water Quality

Depth (meters)	Mean Depth(m)	n	Hardness mg l^{-1}	Sulfates mg l^{-1}	Nitrates[2] mg l^{-1}	Conductivity $\mu S\ cm^{-1}$	Milk Production[1] (kg $cow^{-1}d^{-1}$)
0 - 15	8.9	183	748.4[ab5]	396.7[c]	54.2[a]	1533.9[c]	19.9[c]
15.5-30	23.3	113	899.4[a]	637.8[b]	15.0[b]	1833.6[bc]	20.1[bc]
30.8-61	46.7	114	852.0[ab]	695.6[ab]	4.2[b]	2028.6[b]	21.2[abc]
61.2-91	78.3	67	684.4[bc]	870.9[a]	2.7[b]	2704.1[a]	21.4[a]
91.7-122	104.8	47	509.4[cd]	747.0[ab]	2.8[b]	2480.4[a]	21.3[ab]
>122	178.8	30	342.2[d]	430.8[c]	6.8[b]	2544.8[a]	21.4[ab]
Mean	45.3		750.7	595.9	22.8	1971.4	20.4
SD	46.9		472.9	508.7	61.9	1083.4	3.9
SEM	1.4		14.2	15.2	1.8	32.6	0.1
Prob. of Differences Between Depth-Groups.			< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Recommended Maximum[3]			-	1000	22.7	3000[4]	

[1]Holsteins only. Significant mean separation occurred (Scheffe's test) when the last two well-depth groups were combined.
[2]Nitrates plus nitrites expressed as nitrate-nitrogen.
[3]Canadian Water Quality Guidelines 1987.
[4]TDS mg l^{-1}
[5]Means (within columns) bearing different superscripts were significantly different ($P < 0.05$).

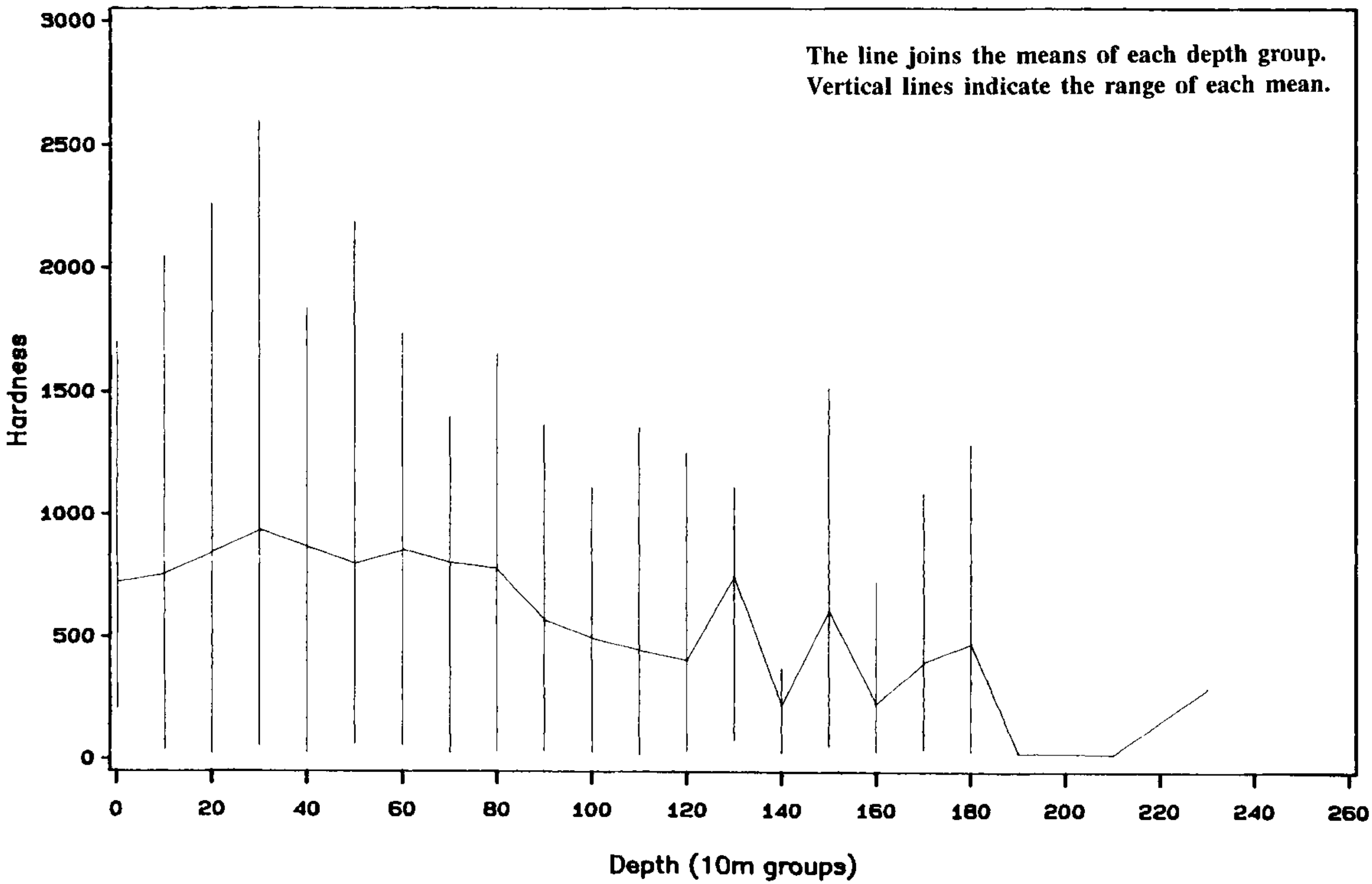


Figure 4.1: Hardness (mg/l) vs Depth of Well

If one considers the hardness ratings for domestic drinking water (NAS 1974) (Table 4.6) then most Saskatchewan dairy farm water is extremely hard with an average of 750.7 mg l^{-1} hardness (Table 4.5). In this survey 89.9% of farms had hardness in their water of over 180 mg l^{-1}.

Table 4.6: Hardness Rating for Domestic Drinking Water

Hardness Range (mg l^{-1})	Description
0 to 60	Soft
61 to 120	Moderately Hard
121 to 180	Hard
> 180	Very Hard

No guidelines exist for maximum levels of hardness as it relates to livestock (Canadian Water Quality Guidelines 1974), however, the levels of Ca and Mg (the main components of hardness) are important. The suggested maximum levels of Ca in water is 1000 mg l^{-1}. The levels of hardness found in this survey could have a significant effect on machinery including dairy equipment (NAS 1974). Hard water will form scale on heated surfaces (unless preventative measures are taken) thus reducing the diameter of water and milk pipes and reduce the efficiency of soaps.

4.1.1.2 Sulfate

Sulfates increase with increasing well depths to about 90 m then sulfate concentration decreases with depth as shown in Figure 4.2 and Table 4.5. Price (1985) indicates that as the water moves deeper in an aquifer sulfate ions increase in importance and become dominant. At deeper levels there is a decrease in dissolved oxygen in the water which slows the reduction of sulfate salts to sulfate. Thus, as the aquifer deepens or the water travels further in the aquifer there is less and less sulfate present in the water (Ward et al. 1985).

Sulfate levels found on these farms were, on average, below the recommended maximum of 1000 mg l^{-1}. However, the Canadian Water Quality Guidelines (1987) suggest that levels of sulfate greater than 500 mg l^{-1} can accentuate Cu, Zn, Fe or Mn deficiencies. In this survey 116 farms (16.8%) had water sulfate levels greater than 1000 mg l^{-1} with 6 of these farms (0.9%) having sulfate levels greater than 2000 mg l^{-1}.

4.1.1.3 Nitrate

Nitrate levels were found to decrease with increasing well depth (Figure 4.3 and Table 4.5). This may have been due to a decrease in dissolved oxygen levels resulting in denitrification of the nitrate in the water (Ward et al. 1985). The presence of nitrate in water from a very deep well could be due to contamination of the water at or near the surface or contamination of the well due to leaking well casings or seals (van der Kamp 1989).

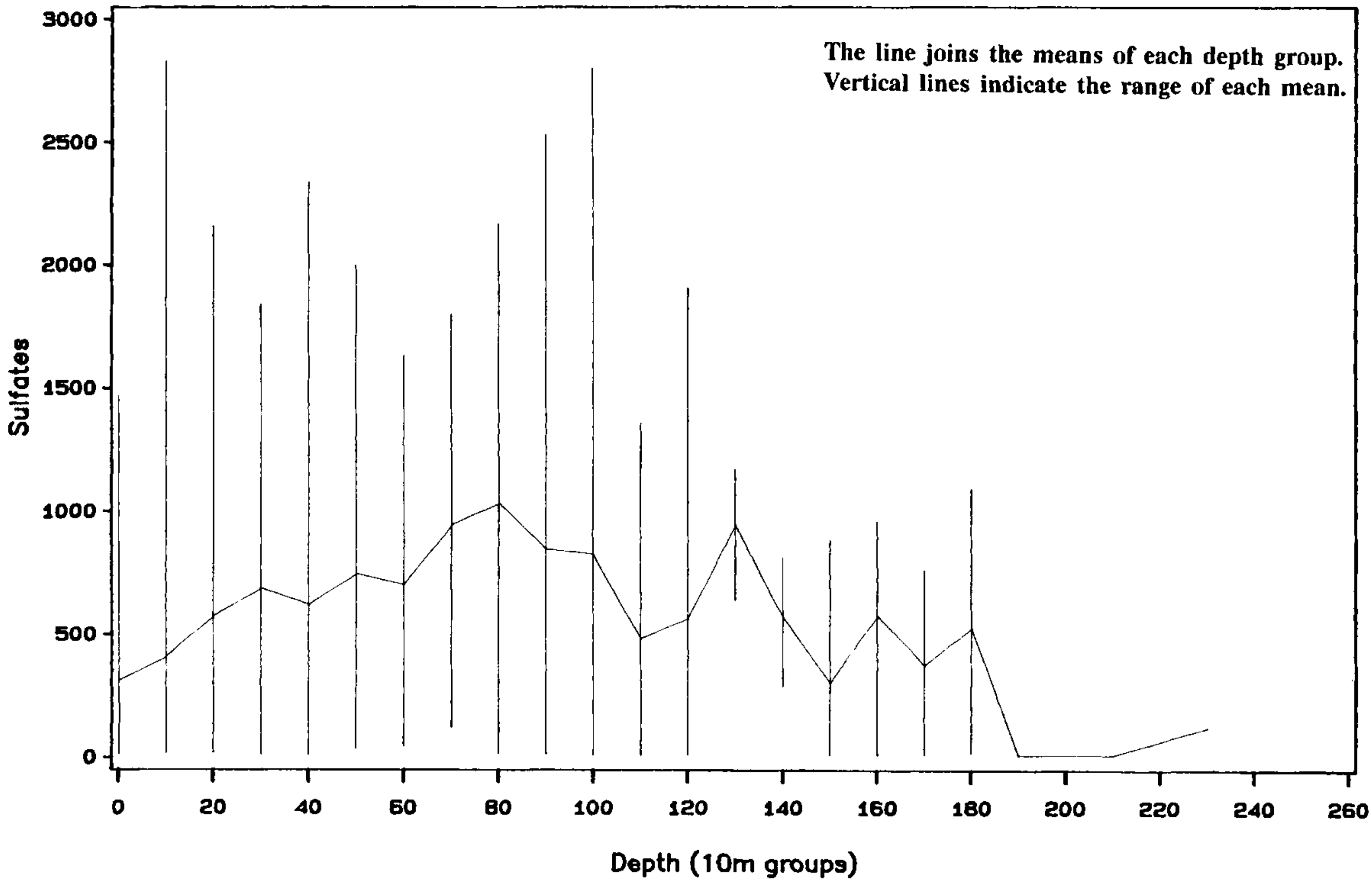


Figure 4.2: Sulfate (mg/l) vs Depth of Well

The average nitrate levels found in this survey slightly less than the 22.7 mg l^{-1} (nitrate plus nitrite expressed as nitrate-nitrogen) maximum recommended for livestock in the Canadian Water Quality Guidelines (1987). However, these averages do not show the many farms which had very high levels of nitrate. Twenty-six farms had water containing greater than 100 mg l^{-1} NO_3. Of these farms the highest level of NO_3 was 670 mg l^{-1}. This water could cause serious problems for both people and animals.

4.1.1.4 Conductivity

In this survey conductivity was considered to be equivalent to the TDS content of the water. The conductivity of the water in this survey increased with increasing well depth up to 90 m then stabilized (Figure 4.4 and Table 4.5). Theoretically conductivity should increase as the aquifer goes deeper underground or as the water has to travel further in the aquifer (Price 1985). However, at some time (or depth) saturation of the water by minerals does occur.

The average levels of conductivity found on dairy farms inthis survey (1971.4 μS cm^{-1}) is at a level (1000 to 3000 mg l^{-1} TDS) which the NAS (1974) suggests would be satisfactory for all classes of livestock. However, this level of conductivity could cause temporary and mild diarrhea in livestock not accustomed to it.

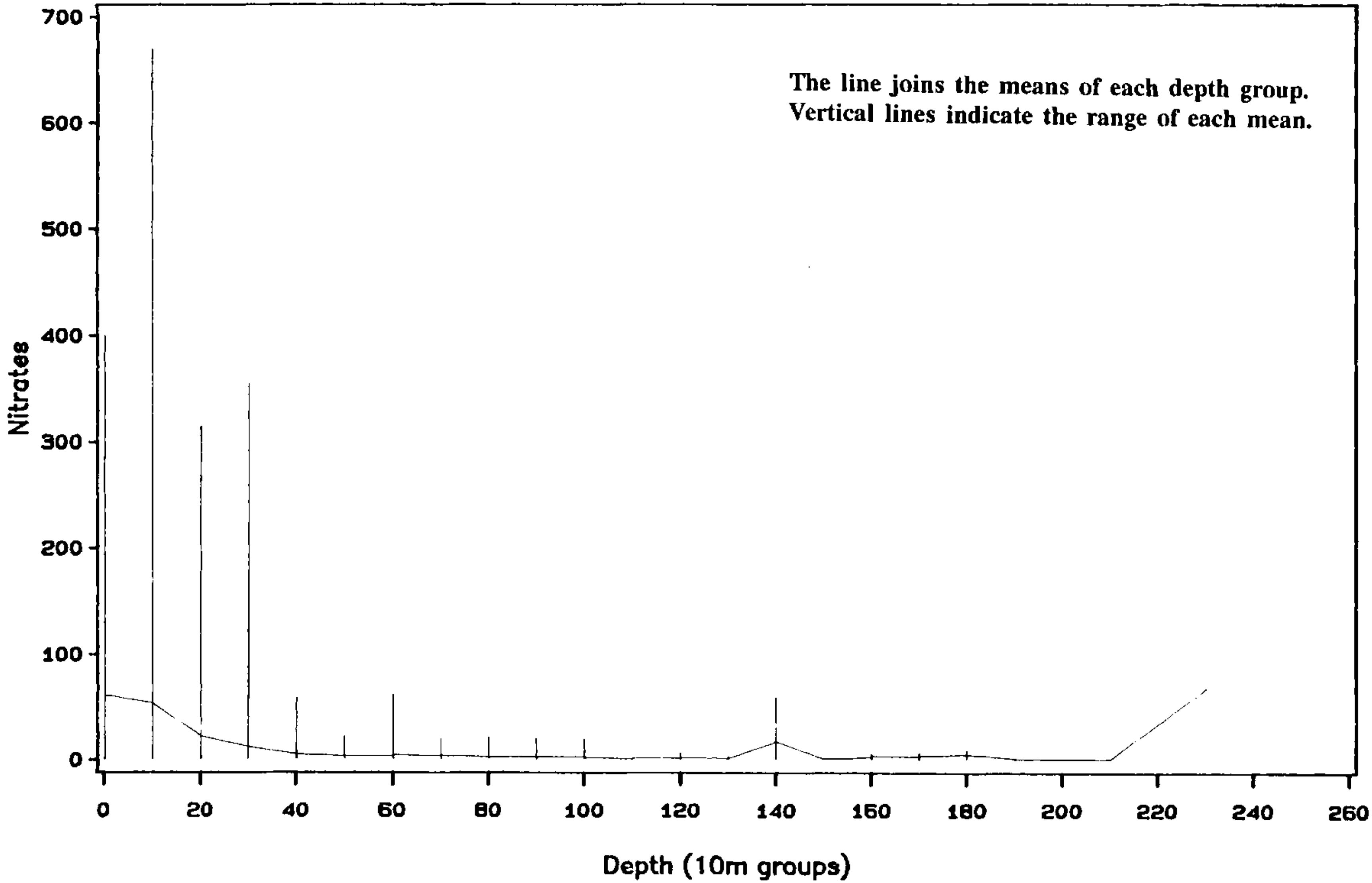


Figure 4.3: Nitrates (mg/l) vs Depth of Well

Water with higher conductivity did exist on some dairy farms. Seventy-five farms (10.7%) had water containing greater than 3000 $\mu S\ cm^{-1}$ conductivity and 9 of these farms (1.2%) had water containing greater than 5000 $\mu S\ cm^{-1}$. The highest level of conductivity found in this survey was 7235 $\mu S\ cm^{-1}$ which the NAS (1974) considers unfit for poultry and swine and a considerable risk for pregnant or lactating cows.

4.1.2 The Effect of Water Quality on Milk Production

The use of bulk tank amount of milk for calculating milk production per cow per day provides an estimate of yield. The bulk tank reading reflects only the amount of milk that the producer actually sells. This amount does not include colostrum, milk from antibiotic treated cows, milk fed to calves and milk retained for home use. Therefore, the calculated production data underestimates average daily milk production per milking cow in the herd.

As seen in Table 4.5 there is some effect of well depth on milk production. From this data it would appear that as welldepth increased milk production increased. This increase in milk production is small and only significant between the shallow wells (<15 m) and the deep wells (>61 m). One explanation for this increase in production with increasing well depth is that producers with deep wells (>78 m) recognize that the water may not be as good for their cows as water from shallow wells and compensate by being better managers. However, producer opinion

Figure 4.4: Conductivity (uS/cm) vs Depth of Well

of their water quality was not recorded and thus no conclusions can be drawn involving their opinions.

Nitrates also occur in shallow wells and this may be the cause of the lower production on farms with the more shallow wells. However, when stepwise regression was done on the data nitrates did not appear in the equation.

The effect of the various water quality parameters on milk production is not clear from the results of this survey. Stepwise regression analysis performed on Holstein milk production data and well water quality resulted in only hardness entering into the equation. No other water quality parameter met the 0.15 significance level for entry into the model. The analysis indicated a very small negative effect of hardness on production ($r^2 = 0.0158$, $P < 0.01$). Thus the regression analysis suggests that water quality has a very small but significant effect on milk production and that this effect is the result of the amount of hardness in the water.

3.2 Conclusions

The typical dairy farm in Saskatchewan has 42 milking Holstein cows producing 21 kg of milk per d. The herd has a 39% chance of using DHAS or ROP (now they would be using SDHIC). The typical dairy farm's livestock drinking water would come from a well and would contain 750 mg l^{-1} hardness, 596 mg l^{-1} sulfates, 22 mg l^{-1} nitrates and 1,971 $\mu S\ cm^{-1}$ conductivity. Regression analysis suggests that the level of hardness in the water will have a small but significant negative effect on milk production.

From this survey well depth is equivalent to aquifer depth because the variation in water quality parameters with well depth follows the same pattern as would be expected in an aquifer. Hardness and sulfates increased and then decreased with well depth. Nitrates were usually found in shallow wells (less than 33m) with nitrates in the deep wells probably being the result of contamination. Conductivity of the water also increases with well depth and then levels off.

While the results from this survey were inconclusive as to the effect of water quality on dairy cattle milk production they were not unexpected. The reasons for the inconclusive result was that the measurement of milk production contained a degree of inaccuracy because individual cow milk production was estimated from herd total milk production.

5. SURVEY TWO

5.0 Introduction

Survey Two was initiated to provide more accurate data than Survey One on the effects of water quality on the dairy cow. Individual cow data was collected on 12 farms with a range of water-sulfate levels. The data collected included milk production and composition, reproductive information, blood analysis and feed intakes. Feed and water samples were taken and analyzed and nutrient intakes were estimated for each cow.

5.1 Materials and Methods

Twelve dairy farms were selected for use in Survey Two based on the following criteria: 1) Sulfate content of farm water (determined from the previous survey) so that a wide range of sulfate content could be included. 2) Use of herds that participated in the Western College of Veterinary Medicine (WCVM) herd health program. 3) Adequate production (DHAS or ROP) and reproduction records. 4) Proximity to Saskatoon if not in the WVCM program.

Farms were first visited between January and March 1988. At this time a sample of water which the cows usually drank was collected in clean one liter glass jars, stored at 4°C for up to 24 hr and shipped to the Water Quality Laboratory in Regina for analysis of sulfates, nitrates, conductivity, total hardness, pH, calcium, magnesium and sodium using procedures outlined in Table 5.1.

Table 5.1: Water Testing Procedures

Parameter	Method	Reference
Hardness	EDTA color indicator	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
Calcium	EDTA color indicator	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
Magnesium	EDTA color indicator	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
Sodium	Atomic Absorption	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
Alkalinity	Titration with H_2SO_4	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
pH	pH meter before titration for alkalinity	Standard Methods for Examination of Water and Wastewater, 1985, 16th ed.
Sulfate	Automated Methlythymol Blue	Analytical Methods Manual, Environment Canada - Inland Waters Directorate 1979
Nitrates	Conversion of nitrate to nitrite to nitrous acid then diazotization.	Water Quality Laboratory, 1988
Conductivity	YSI model 35 conductance meter	Water Quality Laboratory, 1988

On each farm milking cows were selected for evaluation if they were in their second or later lactation and less than 120 days in milk.

Production and reproduction data on each cow were collected on the first visit and on a follow-up visit approximately one month later. Production records including kg milk, percentage fat, percentage protein, body weight (if accurately and recently estimated) and if available BCA fat and milk and projected milk production were obtained from DHAS or ROP records from the test day closest to the visit. Reproductive records, if available, were taken from farm records. Reproduction data included the cow's date of birth, current calving date, date of first heat, date of first service, date of last service and the number of services.

Feed samples were collected in plastic bags and immediately taken to the Saskatchewan Feed Testing Lab. Samples were tested for moisture, crude protein (CP), total digestible nutrients (TDN), calcium (Ca), phosphorus (P), pH (of silages), nitrates (on forages), copper (Cu), zinc (Zn), molybdenum (Mo), chloride (Cl), sulphur (S), and iron (Fe) using procedures outlined in Table 5.2. Feeds were not analyzed for Na since most feeds are low in Na (NRC 1989). It was also not possible to estimate free-choice salt/mineral intake and thus Na intake from these sources under farm conditions. Producer-estimated feed intakes of the cows used in the study were collected.

Table 5.2: Feed Testing Procedures

Parameter	Method	Reference[1]
Dry Matter	135°C, 2 hrs.	7.007
TDN	Calculated	Adams, R.S.
Crude Protein	Autoanalyzer	7.025
Calcium	Autoanalyzer on the same digest as Crude Protein on a system developed by Technicon.	
Phosphorus	As for calcium.	
Sulfur	On a 3410 ICP made by Applied Research Laboratories	
Copper	Atomic Absorption	3.006
Zinc	Atomic Absorption	7.096
Iron	Atomic Absorption	7.096
Molybdenum	Colorimetric	3.041
Nitrates	Modified procedure developed in the Saskatchewan Feed Testing Laboratory, Saskatoon, Sask.	

[1]Numbers refer to reference numbers in: AOAC, 1984

Blood samples were collected from the tail vein into two vials: 1) non-heparinized[1] 2) sodium-heparinized[2]. The samples were stored at 4°C for a minimum of four hours then centrifuged for 15 min.. Serum and plasma were then drawn off

[1]"Vacutainer" Red-stopper, silicon coated, no additive. Made by Becton-Dickinson Canada Inc., Mississauga, Ont. L5J 2M8.

[2]"Vacutainer" Dark-blue stopper. no interior coating, contains Sodium Heparin. Made by Becton-Dickinson Canada Inc., Mississauga, Ont. L5J 2M8

into plastic vials. Serum was sent to WCVM Clinical Pathology Laboratory and analyzed for Sodium (Na), Potassium (K), Chloride (Cl), Carbon dioxide (CO_2), Anion gap, Phosphorus (P), Magnesium (Mg), Urea, Creatinine, Glucose, Bilirubin, Alkyl phosphatase, Creatinine phosphokinase (CPK), Aspartase aminotransferase (AST), Gamma glutamyltransferase (GGT), Protein, Albumin and A-G ratio using procedures outlined in Table 5.3. Plasma was stored at -40°C and later tested for Cu and Zn using the HCl/TCA method (Sunderman, 1975).

Statistical Analysis

All data was first transferred to a custom-designed record keeping system on "DataEase"[3] . Here the data was checked and manipulated on forms shown in Appendix B. This data was then transferred to the VAX-6000 series computer and statistical analysis was performed using SAS (version 5.18).

Statistical procedures were performed on the data from each cow. The GLM procedure and Scheffe's test were used to find significant differences between farms. Pearson correlation analysis was used to find correlations between various parameters.

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[3]"DataEase" Version 2.5, Software Solutions Inc., 12 Cambridge Dr., Trumbull CT.

Table 5.3: Blood Analysis Procedures[1]

Parameter	Method[2]
Sodium and Potassium	Ion Selective electrodes
Chloride	Modified Schoenfeld and Lewellen (mercuric thiocyanide)
Phosphorus	Modified Daly and Ertingshausen
Magnesium	Modified Gindler and Heth, Khayam-Bashi (Calgamite)
Urea	Modified Talke and Schubert (measures urea-N then converts to urea)
Creatinine (A&B)	Kinetic Jaffe reaction
Glucose	Modified CDC national reference method (hexokinase)
Bilirubin	Modified Walters and Gerarde
Alkaline Phosphatase	Modified Bowers and McComb
CPK (CK)	CK-NAC Modified Oliver Rosalki
AST (GOT)	Modified IFCC method
GGT	Modified Szasz
Total Protein	Modified Biuret
Albumin	Modified Doumas (bromcresol green)
A-G ratio	Calculated using Total Protein and Albumin

[1]Blood analysis performed with serum.
[2]All methods refer to those performed on a Coulter DACOS, Coulter Electronics, Hialeah, Florida

5.2 Results and Discussion

5.2.0 General Farm Description

The farms used in this study were similar to the average dairy farm in the province of Saskatchewan. As illustrated in Table 5.4 the average number of milking cows was 46.2. This is higher than the average found in Survey 1 (42.0) and slightly lower than the March 1988 DHAS average of 49.3. Of the 12 farms studied 83% used well water for their cows. This compares with 84% of dairy farms on the provincial survey. Average well depth in this study was 43.0 m and ranged from 5.4 to 99.0 m. The average well depth in the provincial study was 45.1 m.

Six freestall and six tiestall barns were included in this study. It is not known what percentage of cow housing types are used by dairy farmers across the province.

The feeding systems used on the farms varied considerably. All farms used barley either as silage or as part of the concentrate. Silage (usually barley) was used as the main forage source on seven farms. Alfalfa haylage was used on two of the 12 farms (12.2%) with the remaining three farms using a hay/grain diet. Nine farms (75%) used hay (usually alfalfa) as part of their forage with the other three farms (25%) not using hay in the cow's diet.

As a criteria for farm selection the farms were to be on a milk production recording program. In this survey six herds (50%) used DHAS exclusively and five (42%) used ROP exclusively. One herd (12) used both programs. This compares to a provincial

Table 5.4: Survey Two - General Farm Description

Farm Number	Milking Herd[1]	Water Source	Well Depth (m)	Cow Housing Type	Performance Program	Feeding System
1	60	well	76.2	freestall	DHAS[3]	computer feeder, silage/ grain/hay/cottonseed
2	42	well	99.0	tiestall	ROP[4]	silage/grain
3	35	well	27.4	tiestall	DHAS	silage/barley/hay/ protein supplement
4	34	well	21.3	freestall	ROP	barley/haylage/ protein supplement
5	50	well	91.4	freestall	DHAS	computer feeder, silage/ grain/hay
6	28	well	54.8	tiestall	ROP	grain/alfalfa
7	52	well	91.4	freestall	ROP	silage/grain/hay
8	67	well	30.4	tiestall	DHAS	silage/grain/hay/ cottonseed
9	64	dugout	-	freestall	ROP	haylage/barley/ protein supplement
10	30	well	5.4	tiestall	DHAS	barley/alfalfa/ protein supplement
11	45	well	11.0	tiestall	DHAS	barley/alfalfa/ protein supplement
12	55	city	-	freestall	DHAS & ROP	silage/grain/hay/ computer feeder
Mean	46.2	83% wells	43.0	6freestall 6tiestall	6DHAS, 5ROP 1 both	-
Provincial Mean[2]	42.0	84% wells	45.1	-	36.8% DHAS, 13.7% ROP 49.4% no program	

[1]All cows were Holsteins.
[2]Survey One.
[3]DHAS = Dairy Herd Analysis Service, Sask.
[4]ROP = Record of Performance.

Grain = commercially prepared ration
Protein Supplement = commercially prepared high protein (32 or 35% CP) supplement formulated to be fed with barley.

average of 36.8% using DHAS, 13.7% using ROP and 49.4% using no performance program (Survey One). Thus the herds selected had better record-keeping than the provincial herd population.

5.2.1 Water Quality

5.2.1.0 Hardness

The average hardness for this group of farms (727 mg l^{-1}) was close to the 705.2 mg l^{-1} average for the province (Table 5.5). The range of hardness found on these farms was wide (161 mg l^{-1} to 2231 mg l^{-1}) which explains the large standard deviation (609.8). As mentioned previously, no guidelines pertaining to the level of hardness in water for livestock exist in the Canadian Water Quality Guidelines (1987). The NAS (1974) suggests that hardness per se has little effect on livestock but the level of individual ions can be a concern. This is apparent when comparing the two farms with the highest and lowest levels of hardness. The farms with the highest levels of hardness (2231 mg l^{-1}) also has high sulfate, nitrate, conductivity and calcium which are more of a concern to livestock than simply the high hardness. The farm with the low level of hardness (161 mg l^{-1}) had a high level of sodium in the water (880 mg l^{-1}) which is of concern to dairy cows and humans.

Since Total Hardness is determined from the Ca and Mg content it is not surprising that Total Hardness and Ca content are highly correlated ($r = 0.980$, $P < 0.01$).

Table 5.5: Water Composition on Individual Farms

Farm Number	Water Source	Well Depth(m)	Hardness	Sulfate	Nitrate	Cond[3]	Alkalinity	Ca	Mg	Na	pH
			----- mg l^{-1}		-----	$\mu S\ cm^{-1}$	-------- mg l^{-1}		-------		
1	well	76.2	161	340	<1	3760	452	15	-	880	3.1
2	well	99.0	638	750	<1	2080	482	150	64	-	7.6
3	well	27.4	1434	1160	<1	2460	444	250	-	130	8.0
4	well	21.3	2231	2220	52 (60)[1]	4090	2231	445	-	328	7.7
5	well	91.4	584	1200	<1	3620	448	144	-	740	7.8
6	well	54.8	232	690	<1	2530	495	74	12	342	7.7
7	well	91.4	198	1060	<1	3100	552	18	-	705	7.5
8	well	30.4	1416	1470	<1	3080	612	309	-	352	7.8
9	dugout	-	438	358	2 (<1)	896	130	76	-	33	7.8
10	well	5.4	364	91	23 (24)	706	258	110	21	21	7.5
11	well	11.0	629	356	6 (34)	1220	382	152	61	67	7.3
12	city	-	174	84	<1	340	98	24	28	25	7.9
Mean		43.0	727.6	816.4	5.9	2313.3	396.3	148.2	31.6	320	7.3
SD		36.9	609.8	599.9	14.2	1228.3	163.8	122.0	19.2	306	1.2
SEM		3.8	61.9	60.9	1.4	124.7	16.6	12.3	3.0	32	0.1
Provincial[1] Average		45.2[2]	705.2	541.0	19.6	1809.5	-	-	-	-	-
Recommended Maximum[4]			-	1000	22.8	3000[5]	-	1000	-	-	-

1Survey One
2Wells only.
3Conductivity
4Canadian Water Quality Guidelines 1987
5TDS mg l^{-1}

5.2.1.1 Sulfates

One of the criteria for farm selection was to chose a wide range of water sulfate levels. This is reflected in the range of sulfate levels from 84 mg l^{-1} to 2220 mg l^{-1} (Table 4.5). The mean sulfate content for all the farms was 816.4 mg l^{-1} compared to the provincial average of 541.0 mg l^{-1} found in Survey One. The provincial range of sulfate levels in water was 10 mg l^{-1} to 2900 mg l^{-1}. Both of the survey averages are above the maximum guideline for sulfate in domestic water supplies of 500 mg l^{-1} (McNeely et al. 1979) and below the suggested maximum for livestock of 1000 mg l^{-1} (Canadian Water Quality Guidelines 1987).

At levels of sulfate in the water greater than 1000 mg l^{-1} the water can contribute significantly to the sulfur intake of dairy cows. In this survey cows received from 3.4 to 75.7 g of S per day from the sulfate in the water. Of those farms with water containing greater than 1000 mg l^{-1} SO_4 (farms 3,4,5,7 and 8) cows, on average, received a minimum of 29.4 g S d^{-1} which is 73% of their S requirement (see section 5.2.5.2).

5.2.1.2 Nitrates

The nitrate content of these waters was, on average, quite low (mean 5.9 mg l^{-1}) compared to the provincial average of 19.6 mg l^{-1} (Table 5.5). Only four farms (33%) had measurable levels of nitrate. Since the water on all but one of these farms also had measurable levels of NO_3 one year earlier when tested for

Survey One it is assumed that nitrate contamination of these wells was an ongoing problem. On these four farms (Survey Two) the amount of nitrate varied from 2 to 52 mg l^{-1} compared to a provincial range of 0 to 680 mg l^{-1}.

The level of nitrates found on these farms is below the suggested maximum level of 22.7 mg l^{-1} NO_3-N (Canadian Water Quality Guidelines 1987) for livestock. Two farms (4 and 10) had water with nitrate higher than the maximum allowable level of 10 mg l^{-1} for domestic drinking water (McNeely et al. 1987). While these levels are not excessive the water should not be given to infants (McNeely et al. 1987).

5.2.1.3 Conductivity

Conductivity on the farms in this survey averaged 2313.3 μS cm^{-1} which is above the provincial average of 1809.5 μS cm^{-1} (Table 5.5). On five farms (42%) the conductivity of the water was over 3000 μS cm^{-1}.

When comparing the conductivity of the water on these farms to the recommendation of the NAS (1974) for the use of saline water for livestock only three of the 12 farms had water with <1000 μS cm^{-1} conductivity and thus were in the best category of water salinity. Four farms had water containing 1000 to 3000 μS cm^{-1} conductivity which the NAS (1974) considers satisfactory for all livestock but may cause temporary and mild diarrhea. Three farms had water with conductivity >3000 μS cm^{-1}. This level of salinity will cause temporary diarrhea and may be refused at first but is satisfactory for livestock (NAS 1974). There were no observations of diarrhea in the livestock on these farms however mild diarrhea could be the result of a number of conditions and thus diarrhea caused by poor water could be misdiagnosed.

The maximum acceptable level of TDS for human consumption is 500 mg l^{-1} (McNeely et al. 1979). Only one farm in this survey has water with less than 500 $\mu S\ cm^{-1}$ conductivity. The water used on this farm was treated city water of river origin. Eleven of the 12 farms do not meet the requirements for domestic water consumption in relation to TDS (based on conductivity).

The conductivity of water is associated with the presence of substances which dissociate into anions and cations (IHD-WHO 1978). Thus correlations between conductivity, sulfate, nitrate, Ca, Na and pH were performed to measure the extent of the association between these parameters (Table 5.6).

Table 5.6: Water Composition Correlations

	Conductivity	Sulfate	Nitrate	Calcium	Sodium
Sulfate	** 0.76				
Nitrate	-	** 0.44			
Calcium	** 0.46	** 0.86	** 0.59		
Sodium	** 0.81	** 0.30	-	-	
pH	** -0.34	** 0.25	-	** 0.34	** -0.58

Regression analysis was then performed and produced the following equation for the prediction of conductivity from other water composition parameters:

$$\text{Conductivity} = 2214.8 + (1.2 \times \text{Sulfate}) - (3.5 \times \text{Nitrates}) + (2.08 \times \text{Sodium}) - (229.5 \times \text{pH})$$

An example of the closeness of actual conductivity measurement and a calculated estimate is as follows:

Farm #3: Measured conductivity = 2460 $\mu S\ cm^{-1}$
Calculated conductivity = 2041 $\mu S\ cm^{-1}$
Farm #1: Measured conductivity = 3760 $\mu S\ cm^{-1}$
Calculated conductivity = 3742 $\mu S\ cm^{-1}$

A more accurate regression equation would be possible with a larger number of observations.

5.2.1.4 Alkalinity

The alkalinity of the water on the farms in this survey ranged from 98 mg l^{-1} to 2231 mg l^{-1} with a mean of 396.3 mg l^{-1} (Table 5.5). Only three farms (25%) had water that contained levels of alkalinity above the 30 to 500 mg l^{-1} acceptable range for humans (McNeely et al. 1979). However, one farm (farm 4) had water that contained excessive levels of alkalinity (2231 mg l^{-1}) which makes it highly unsuitable for human use as it can cause digestive disturbances (ibid.). The Canadian Water Quality Guidelines (1987) do not mention alkalinity as it relates to livestock water quality.

5.2.1.5 Calcium

Water calcium (Ca) levels in this survey ranged from 15 mg l^{-1} to 445 mg l^{-1}) with a mean of 148.2 mg l^{-1} (Table 5.5). All farms in this survey had levels of Ca below the recommended maximum for livestock of 1000 mg l^{-1} (Canadian Water Quality Guidelines 1987). However, three farms had levels of Ca greater than the 300 mg l^{-1} maximum allowable level for domestic water consumption (McNeely et al. 1979). While for humans high levels of Ca could be beneficial in the prevention of cardiovascular disease (Crawford 1972) high levels of Ca in the water also produces scale on heated surfaces and reduces the efficiency of soaps (NAS 1974). The higher levels of water Ca can also contribute significantly to meeting the cow's requirement for Ca (see section 5.2.5.1).

5.2.1.6 Sodium

The mean sodium (Na) content of farm water in this survey was 320 mg l^{-1} (Table 4.5). Three farms (1,5 and 7) used water that contained over 700 mg l^{-1} of Na. These high levels of Na were all associated with conductivity levels greater than 3000 mg l^{-1} resulting in a high correlation between conductivity and Na ($r = 0.81$, $P < 0.01$) (Table 4.6). No mention of maximum levels of Na in water for livestock is made in the Canadian Water Quality Guidelines (1987), by McNeely et al. (1979) or by the NAS (1974). For humans the maximum acceptable levels of Na for domestic consumption is 270 mg l^{-1} (McNeely et al. 1979). Thus five of the 12 farms would not meet this water quality requirement for humans. High levels of Na in the water can contribute significantly to the cow's Na intake. In this survey cows consuming average quality water received their entire daily Na requirement from the water (see section 5.2.5.3).

5.2.1.7 Magnesium

The amount of Mg in the water was not measured on all farms (Table 4.5). However, the levels found are low compared to a lactating cows requirements. For example, if the average cow in this survey consumed 20 kg DM d^{-1} then its requirement for Mg is 40 g d^{-1} (NRC 1989). At the highest level of Mg in water encountered on this survey (64 mg l^{-1}) and with a cow drinking 80 l d^{-1} then the cow would receive 5.1 g Mg d^{-1} from the water or 12.8% of its requirement.

5.2.1.8 pH

The mean pH of waters in this survey was 7.3. One farm (farm 1) had water with a pH of 3.1 (Table 5.5). This water was also relatively soft (Hardness = 161 mg l^{-1}) and had a high level of sodium (880 mg l^{-1}). The reason for the unusually low pH found on this farm is not known. Possible explanations are contamination of the sample or contamination of the water supply. The farm's water was retested for pH one year later and the pH was 7.9. More information on this farm's water is presented in Appendix C.

The pH of fresh water ranges from 4 to 9 with surface water tending to be more alkaline and ground water more acidic (McNeely et al. 1979). Eleven of the 12 farms tested in this survey fall within this range.

No guidelines have been established for an acceptable range of pH for livestock (Canadian Water Quality Guidelines 1987). However the acceptable range of pH for human drinking water is 6.5 to 8.3 (McNeely et al. 1979). Only one farm of the 12 in this survey has water with a pH outside of this range.

5.2.2 Reproduction Data

The average reproductive data for each farm is summarized in Table 5.7. Even though farms were selected partially on the basis of record-keeping ability the quality of reproductive records was, in most instances, less than ideal. Many cows had incomplete reproductive records and many records contained data that was unreliable. Thus, due to inaccuracies in the reproductive data I have reservations when making conclusions from statistical analysis involving this data.

As an example of some of the inaccuracy days to first heat (DFH) often did not reflect the true days to first heat because many producers do not observe or record the very first heat. The DFH tended to be the 'Days to first noticed, recorded and planned breeding heat'.

Days to first service (DFS) may also not be very accurate as it was often the same as DFH. This is evident in farm 8. The

Table 5.7: Reproduction Data: by Farm

Farm Number	Cows Observed	Days to 1st heat	Days to 1st serv	Services/ Conception	Days Open
1	8	53.2	93.1[ab]	(2)[1] 1.0	83.0
2	10	54.1	75.7[ab]	(5) 1.2	84.6
3	10	68.8	71.3[ab]	(4) 2.0	89.7
4	7	59.6	95.8[ab]	(6) 1.6	108.8
5	10	42.4	80.5[ab]	(10) 1.3	89.9
6	7	41.0	99.0[ab]	(3) 1.6	96.3
7	5	64.5	112.7[a]	(0)	
8	9	72.8	72.8[ab]	(8) 2.4	131.3
9	7	52.3	63.0[b]	(3) 1.3	87.3
10	7	49.7	62.1[b]	(3) 1.0	56.3
11	7	60.1	83.0[ab]	(1) 2.0	91.0
12	10	49.3	74.0[ab]	(9) 1.8	112.7
Mean	8.0	56.5	79.7	(54) 1.59	99.5
SD		26.3	21.6	0.77	36.5
SEM		2.9	2.4	0.10	4.9
Average (Optimum)[3]		66(48)	84(<60)	1.6-2.0	120(85)
Probability of Differences between farms		NS	< 0.01	NS	NS

[1]Number in brackets = number of cows (of Cows Used) who were confirmed pregnant on the date of the second visit.
[2]March 1988 DHAS Provincial Average.
[3]Wilcox et al. 1978

average DFS was greater (79.7) than the optimum (<60) but less than the expected average (84) (Wilcox et al. 1978). In some herds DFS was excessively high.

Those cows confirmed pregnant by the second visit (number in brackets) were studied to find the numbers of services per conception. All farms used artificial insemination (AI) exclusively. Foley et al. (1972) recommends an optimum of 1.6 services per conception with an average of 2.0 services per conception. In this survey the average services per conception was 1.59 however due to the small sample size on the farms this number may not be a true representation (CV = 48.6).

Days Open (also dependant on those cows confirmed pregnant at the time of the second visit) was slightly lower (99.5 d) than the expected average (120 d). To achieve the optimum 12 month calving interval (Wilcox et al. 1978) a cow must be pregnant 85 days after calving. Few farms on this survey achieved this goal.

DFS and Days Open were significantly correlated ($r = 0.324$, $P < 0.05$). The relationship between these two parameters is shown graphically in Figure 5.1.

The herds used in this study displayed reproductive performance that was in the acceptable range. Possible explanations for their good performance are that the herds chosen emphasized management as evidenced by their record-keeping and participation in DHAS or ROP. These herds were also all on supervised herd health programs and most feed tested.

Significant correlations were found between some

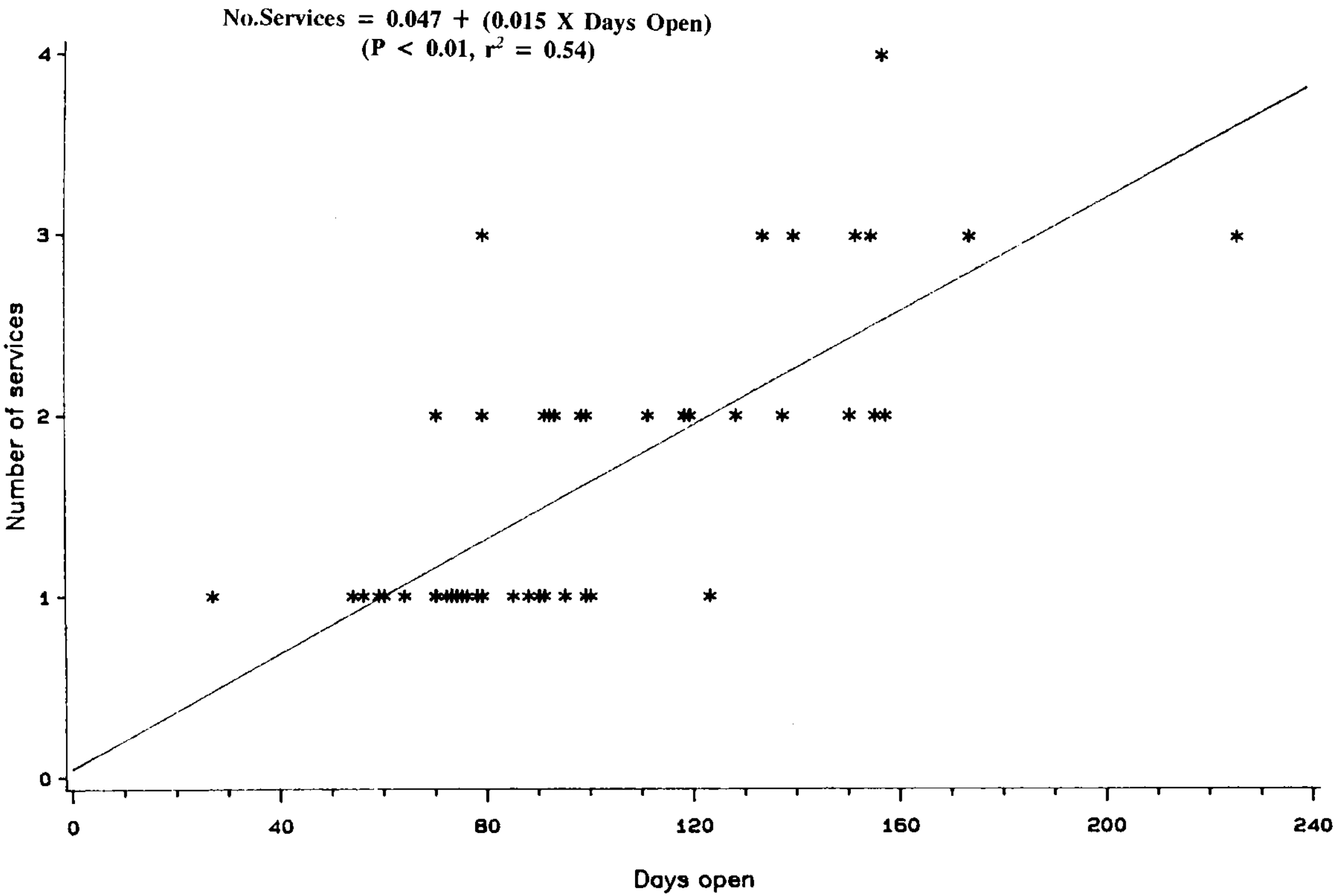

Figure 5.1: Number of Services versus Days Open

reproductive parameters and the water quality parameters (Table 5.8). DFH was significantly correlated to hardness while DFS was significantly correlated to conductivity, alkalinity and sodium. Services per conception was significantly correlated to hardness, calcium (hardness and calcium confound), and pH. Days open was not significantly correlated to any water quality parameters.

5.2.3 Milk Production and Composition

5.2.3.0 4% FCM Production and Days in Milk

In this study the average Days in Milk was 71.4 (Table 5.9) whereas in a complete herd (with cows in all stages of lactation) the optimal average Days in Milk would be 152 (305/2). Cows used in this study were chosen if they were under 120 days in milk thus the Average Days is Milk is not that of a normal herd.

On each farm cows were selected if they were in their second or later lactation and less that 120 days in milk. This selected the relatively high producing cows and eliminated heifers. Heifers were not used in the survey since they may have accumulated Cu reserves during growth and would thus show less of an effect from sulfate content in the water. Early lactation cows were selected because they are under the most stress and thus are more vulnerable to the effects of poor water quality.

The selection of early lactation cows in this survey explains the difference between the study's average 4% FCM production (31.7 kg d^{-1}) and the provincial average

Table 5.8: Correlations of Reproductive and Production Parameters and Water Quality Parameters.

	Conductivity	Hardness	Sulfates	Nitrates	Alkalinity	Sodium	Magnesium	Calcium	pH
Days to First Heat	-	*0.24	-	-	-	-	-	-	-
Days to First Service	**0.36	-	-	-	**0.30	**0.37	-	-	-
Services per Conception	-	*0.28	-	-	-	-	-	*0.26	*0.26
Days Open	-	-	-	-	-	-	-	-	-
4% FCM Production	-	**-0.32	**-0.28	*-0.22	-	-	-	**-0.28	-

* $P < 0.05$
** $P < 0.01$

- not significant

Table 5.9: Herd Average Milk Production and Composition

Farm Number	Number of Cows Observed	Average Days In Milk	4% FCM ($kg\ d^{-1}$)	Milk Fat(%)	Milk Protein(%)	SCC
1	8	78.7	32.7	3.16^{ab}	2.98^{ab}	76250
2	10	74.1	31.6	3.79^{ab}	3.14^{ab}	-
3	10	86.3	28.5	4.03^{a}	2.81^{ab}	297000
4	7	63.1	26.6	3.68^{ab}	2.72^{b}	107142
5	10	82.4	34.4	3.09^{ab}	2.91^{ab}	29000
6	7	66.1	38.3	3.40^{ab}	2.87^{ab}	-
7	5	76.8	25.4	4.01^{a}	3.40^{a}	54750
8	9	113.2	30.1	2.91^{ab}	2.96^{ab}	151111
9	7	50.4	28.1	2.42^{b}	2.88^{ab}	57142
10	7	54.1	30.9	3.53^{ab}	2.89^{ab}	-
11	7	57.4	35.3	3.61^{ab}	2.98^{ab}	-
12	10	43.0	36.0	4.04^{a}	3.13^{ab}	302857
Mean	8.0	71.4	31.7	3.47	2.96	140629
SD		37.4	6.4	0.76	0.30	392111
SEM		3.8	0.65	0.07	0.03	49798
Probability of differences between farms		< 0.01	NS	< 0.01	< 0.05	N.S.
Provincial Average[1]			22.0			

[1]March 1988 DHAS Provincial Average.

(22.0 kg d^{-1}). The provincial average uses data from cows in all stages of lactation while this study used only cows that were under 120 in milk. It must be noted that only two herds (farms 12 and 1) had milk production recording devices in place full time and recorded this production daily. Production records for cows on the other farms was collected from the DHAS or ROP records on the test day closest to the date of the first visit.

There were no significant differences between farm milk production means using Scheffe's test for mean separation. This was due to the narrow range of milk production found in this survey.

As seen in Table 5.10 4% FCM production is negatively correlated with Days in Milk ($r = -0.38$, $P < 0.01$). Thus as Days in Milk increase 4% FCM production decreases (Figure 5.2). Ideally a cow's milk production should increase in early lactation to peak between one and two months after calving and then milk production declines to the end of that lactation (Wilcox et al. 1978). Since this data set includes cows up to 120 days post calving then perhaps there was an overall decline in milk production over this period or the expected decline after 30 to 60 days was quite large and overshadowed the increase in the first 30 to 60 days.

Stepwise regression showed that of all the water quality parameters nitrates was the only one to have a significant effect on 4% FCM yield. However, correlation analysis indicated that hardness ($r = -0.32$, $P < 0.01$), sulfates ($r = -0.28$, $P < 0.01$),

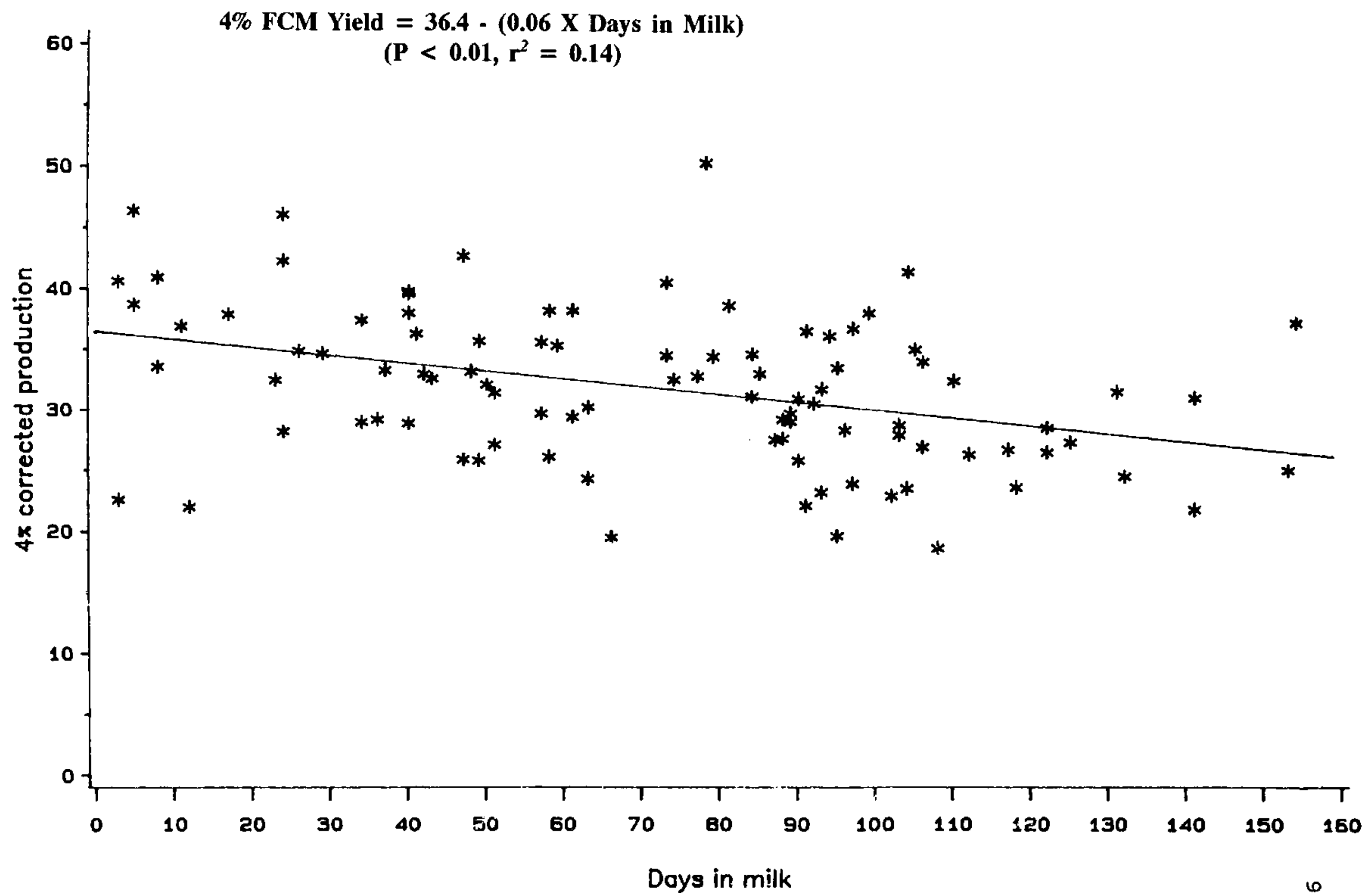

Figure 5.2: 4% FCM Production (kg/cow/d) versus Days in Milk

Table 5.10: Correlations of Major Nutrients and Milk Production and Composition

	4%FCM	DaysinMilk	Lact.No.	Milk Prot.	Milk Fat	DMI	Prot. I	Nitrate I	Mo I	Iron I
Days in Milk	**-0.38									
Lactation Number	-	-								
Milk Protein %	-	-	-							
Milk Fat %	**0.36	-	-	*0.20						
Dry Matter Intake	**0.34	-	-	-	-					
Protein Intake	**0.36	-	-	-	-	**0.90				
Nitrate Intake	-	-	-	-	-	-	-			
Molybdenum Intake	**0.27	-	-	-	-	**0.52	**0.67	-		
Iron Intake	**0.29	-	-	-	**-0.23	**0.68	**0.82	**0.33	**0.42	
Plasma Copper	-	* -0.23	-	-	-	-	-	-	**0.32	-

* P < 0.05   - not significant
** P < 0.01

nitrates ($r = -0.22$, $P < 0.05$) and calcium ($r = -0.28$, $P < 0.01$) were significantly correlated to 4% FCM yield. The equation resulting from the stepwise regression procedure was:

4% FCM yield = 36.9 - (0.26 X nitrates) ($r^2 = 0.14$, $P < 0.05$)

Stepwise regression also showed a significant effect of Days in Milk as well as DMI on 4% FCM yield. The resulting equation from this procedure was:

4% FCM yield = 26.3 - (0.07 X Days in Milk) + (0.52 X DMI)
($r^2 = 0.28$, $P < 0.01$)

In this stepwise procedure the intakes of protein, nitrates, sulfur, Cu, Zn and Fe did not enter the equation. As well, when using all the parameters plus the parameters squared DMI was replaced with DMI squared ($r^2 = 0.30$, $P < 0.01$).

5.2.3.1 Milk Fat Percent

The mean milk fat percentage produced by cows in this survey was 3.47% (Table 5.9) and ranged from 1.55% to 5.19% for individual cows. The overall mean is lower than the 3.6% average expected for Holstein cows (Foley et al. 1972). This overall lower milk fat percentage may be the result of choosing cows for the study that were high producers and in early lactation.

Milk production and milk fat percentage are usually negatively correlated thus as milk production increases fat percentage decreases (Russell 1974). In this survey 4% FCM yield and milk fat percentage were positively correlated ($r = 0.36$, $P <$

0.01) (Table 5.10). This could be due to a number of factors. One is that the negative correlation usually found is calculated on an individual cow basis where the cow's production and milk fat percentage are recorded over the course of a lactation. In contrast, this survey measured a cow's milk production and fat percentage only once in the first 120 days of a lactation. Thus if low producing, low fat cows are included with high producing, high fat cows then it will appear that milk production and fat percentage are positively correlated. There are significant differences between farms as to milk production, fat percentage and protein percentage (Table 5.9). This reflects differences in management, feeding and genetics between farms.

5.2.3.2 Milk Protein Percentage

The mean milk protein percentage found on farms in this survey was 2.96% with a range of 2.21 and 3.84% (Table 5.9). This average is lower than the 3.1% expected for Holstein cows (Foley et al. 1972). Milk protein was found to be not significantly correlated with 4% FCM production (Table 5.10) but was positively correlated with milk fat percentage ($r = 0.20$, $P < 0.05$). The positive correlation between milk fat percentage and protein percentage is expected due to the genetic correlation between the two parameters (Wilcox et al. 1978).

5.2.3.3 Somatic Cell Count (SCC)

The testing of milk for the level of somatic cells is an option in the DHAS and ROP milk recording programs. Four farms did not use the SCC option. Of the eight remaining farms the mean SCC was low (140,629) (Table 5.9) compared to the maximum allowable level of SCC is 750,000. However, there was high variability within and between farms as evidenced by the high standard deviation (392,111) and the wide SCC range for individual cows (10,000 to 2,500,000). Only two cows in the survey (on two different farms) had SCC over 1,000,000. These cows had clinical mastitis and were either treated or sold soon after the survey.

5.2.3.4 Lactation Number

No correlations were found between lactation number and other parameters (Table 5.10). Since only cows in the second lactation or greater were selected for use the lack of correlation is probably due, in part, to the lack of variability in lactation numbers (Table 5.11). Normally milk production would be expected to increase with each lactation up to the fourth and then begin to decline (Wilcox 1978).

Table 5.11: Lactation Numbers of Cows in Survey Two

Lactation Number	Number of Cows	Percentage of Total
2	28	28.9
3	22	22.7
4	30	30.9
5	9	9.3
6	5	5.2
> 6	3	3.0

5.2.4 Farm Average Intakes of Dry Matter (DM), TDN and Protein

5.2.4.0 Introduction

Farm average intakes of the major nutrients: DM, TDN, and protein are listed in Table 5.12. Overall, the intakes are remarkably close to those recommended by the NRC (1988) for the average cow (500 kg, 31.7 kg milk d^{-1}). Among herds and cows there was wide variability in nutrient intakes. This could reflect inaccurate estimation of feed intakes and weighing of feeds.

5.2.4.1 Dry Matter Intake

The DMI (Dry Matter Intake) of individual cows varied from 10.5 kg d^{-1} to 28.1 kg d^{-1} (Table 5.12). This is possibly due to inaccurate estimation of the intakes of various feeds. This is particularly evident on farm 7 whose average estimated DMI was 11.9 kg d^{-1}. This level of intake will not support the 25.4 kg d^{-1} average milk production on this farm especially since the milk production varied from 18.6 to 32.1 kg d^{-1} 4% FCM. The NRC (1988) requirements for lactating cows recommends a minimum of 20.1 kg DMI d^{-1} for a cow producing 32.1 kg 4% FCM d^{-1}. Thus on this farm the estimation of DMI was in all likelihood incorrect. The poor estimation of DMI could be due to the housing and feeding situation on this farm (Table 4.6). On this farm cows were fed free choice silage and hay with a commercially formulated grain fed in the parlor of the freestall barn. It is possible that the

Table 5.12: Farm Average Intakes of Dry Matter, TDN and Protein

Farm Number	4% FCM yield ($kg\ d^{-1}$)	DMI (kg)	DMI as a percent of body weight	TDN (kg)	TDN as a percent of requirement	Protein (kg)	Protein as percent of requirement	Percent CP in DM
1	32.7	21.3^{b}	4.0	15.2^{bc}	106.6	3.9^{bc}	118.5	18.3
2	31.6	17.8^{bcd}	3.5	12.5^{cde}	96.7	2.3^{fg}	78.2	12.9
3	28.5	20.9^{bc}	4.6	14.9^{cd}	121.8	2.9^{def}	105.2	13.8
4	26.6	18.0^{bcd}	3.6	11.7^{de}	96.5	2.7^{efg}	100.5	15.0
5	34.4	27.1^{a}	4.2	19.2^{a}	125.1	5.0^{a}	145.7	18.4
6	38.3	27.4^{a}	5.4	18.6^{ab}	118.4	4.5^{ab}	122.8	16.4
7	25.4	11.9^{e}	2.3	7.9^{f}	67.6	2.0^{g}	79.2	16.8
8	30.1	20.2^{bcd}	4.3	14.2^{cd}	109.6	3.2^{cde}	108.3	15.8
9	28.1	19.2^{bcd}	3.8	12.5^{cde}	98.7	3.5^{cde}	122.4	18.2
10	30.9	16.0^{cde}	3.5	11.6^{de}	88.2	2.6^{efg}	87.3	16.3
11	35.3	15.0^{de}	2.6	9.6^{ef}	63.8	2.8^{efg}	79.9	18.6
12	36.0	20.8^{bc}	3.2	-	-	3.8^{bcd}	104.0	18.2
Mean	31.7	20.1	3.8	12.4	99.4	3.3	104.3	16.6
SD	6.4	4.6	0.8	5.3		0.92		1.9
SEM	0.6	0.4	0.08	0.5		0.09		
Recommended Levels[1]		20.0	4.0	13.9		3.2		16.1
Probability of Differences Between farms		< 0.01		< 0.01		< 0.01		

[1]500 kg cow @ 31.7 kg of 4% milk - NRC 1989.

manager/owner underestimated the intake of both silage and hay. DMI was found to be correlated with several other parameters in the survey (Table 5.10 and Table 5.13). DMI and 4% FCM production were positively correlated ($r = 0.34$, $P < 0.01$) which was expected. DMI was also correlated with intakes of other nutrients. These include Protein intake ($r = 0.90$, $P < 0.01$), Molybdenum intake ($r = 0.68$, $P < 0.01$), Iron intake ($r = 0.68$, $P < 0.01$), Copper intake ($r = 0.58$, $P < 0.01$), Zinc intake ($r = 0.79$, $P < 0.01$) and Sulfur intake ($r = 0.67$, $P < 0.01$). The reason for these correlations is that since these nutrients are contained in the dry matter of the feed then as the intake of DM increases so does the intake of the nutrients. Thus confounding was occurring and the correlations had no meaning.

The calculation for DMI as a percent of body weight was used as a check for the accuracy of feed intake measurements. In most cases this check indicated that all cows were consuming between 3 and 5% of their body weight per day as DM. Depending on the cow's level of production this is reasonable (NRC 1989).

5.2.4.2 Total Digestible Nutrients Intake

The TDN (Total Digestible Nutrients) intakes of cows in this survey followed the same pattern as for DMI (Table 5.12). That is, those farms with low DMI also have low TDN intakes. The mean TDN intake (12.4 kg d^{-1}) is lower than the recommended 13.9 kg d^{-1} for the average cow (NRC 1989) however the range of TDN intakes was wide (6.3 to 19.9 kg d^{-1}). TDN intakes expressed as a

Table 5.13: Correlations between Feed DM and Mineral Intakes and Plasma Cu and Zn

	4% FCM (kg d^{-1})	DMI	Copper Intake	Sulfur Intake	Mo Intake	Zinc Intake	Iron Intake	Plasma Copper
Dry Matter Intake	**0.34							
Copper Intake	* 0.20	**0.58						
Sulfur Intake	-	**0.67	**0.64					
Molybdenum Intake	**0.27	**0.52	-	* 0.24				
Zinc Intake	* 0.25	**0.79	**0.79	**0.65	**0.28			
Iron Intake	**0.29	**0.68	**0.68	**0.48	**0.42	**0.86		
Plasma Copper	-	-	-	-	**0.32	-	-	
Plasma Zinc	-	-	-	-	-	-	-	-

* $P < 0.05$ - not significant
** $P < 0.01$

percentage of each cow's requirement indicate that each farm was consistent at either over or underfeeding TDN (Table 5.12). Six out of 11 farms, on average, underfed TDN to these particular cows.

5.2.4.3 Protein Intake

The mean protein intake in this survey (3.3 kg d^{-1}) was also very close to the recommended 3.22 kg d^{-1} (Table 5.13). However a great range of intakes did occur from 1.3 to 5.1 kg d^{-1}. While the mean protein intake was close to the estimated requirement this meant that six of the 12 farms did not feed adequate protein levels to the cows in their survey group.

When calculated as a percentage of the dry matter content of the diets the mean crude protein (CP) percent of 16.6% is higher than the requirement of 16.1% (NRC 1989). When expressed on this basis, eight of the 12 farms' diets had CP percentages that were higher than the recommended level. However some of these farms did not providing adequate amounts of protein to their cows due to low DMI. This is evident when each cow's protein intake is expressed as a percentage of its requirement. Eight of the 12 farms (Table 5.12) overfed protein to these cows, however, only 57% of the individual cows were overfed protein.

5.2.5 Farm Average Mineral Intake

5.2.5.0 Introduction

In this survey feed samples from each farm were analyzed for the following minerals: Ca, S, P, Cu, Zn, Fe, Mo. The feeds were not analyzed for Na since feeds are generally low in Na (NRC 1989). It was also not possible to estimate free-choice salt/mineral intake and thus Na intake from this source under farm conditions. The intakes of Ca, S, P, Cu, Zn, Fe, and Mo by cows was calculated from the laboratory analysis for these minerals and the dry matter intakes of the various feeds. The results are presented in tables 5.14 and 5.15. Table 5.14 presents the farm average intakes of Ca, S and Na and separates the total intakes into that received from feed and water. This table also presents the percentage of the average cow's Ca requirement that this cow would receive from water and the percentage of the total S intake that the cow would receive from water. Since feed Na content was not analyzed only water Na is presented.

5.2.5.1 Calcium

The mean total Ca intake was 193.7 g d^{-1} which is substantially higher than the 122 g d^{-1} requirement (Table 5.14). Only two farms (2 and 7) fed Ca levels below the requirement. The other farms provided far more than the requirement. Herd average Ca requirement ranged from 101.6 g Ca d^{-1} (farm 7) to

Table 5.14: Farm Average Cow Calcium, Sulfur and Sodium Intake from Feed and Water

Farm	Calcium Intake				Sulfur Intake				Sodium Intake	
	Amount/d (g)			% Requirement	Amount/d (g)			% of Total	Amount/d (g)	% Requirement
Number	Water	Feed	Total	from Water	Water	Feed	Total	from Water	Water	from Water
1	1.8	175.4	177.2[b]	1.4	13.4	72.6	86.2[c]	15.6	104.3[a]	288.1
2	17.3	76.1	93.4[c]	14.2	28.9	32.1	61.0[d]	47.4	-	-
3	26.8	150.7	177.2[b]	24.5	41.6	43.8	85.3[c]	48.7	13.9[de]	38.4
4	45.4	165.3	210.7[b]	43.0	75.7	44.8	120.6[ab]	62.8	33.4[cd]	92.2
5	17.7	254.3	272.0[a]	13.0	49.3	81.8	131.2[a]	37.6	90.9[a]	251.1
6	8.6	304.6	313.3[a]	6.9	27.0	73.2	100.3[bc]	26.9	40.0[bc]	110.4
7	1.4	94.1	95.6[c]	1.8	29.4	32.4	61.8[d]	47.5	58.4[b]	161.3
8	34.4	173.8	208.1[b]	29.8	54.7	47.4	102.1[bc]	53.6	39.1[bc]	108.0
9	8.0	183.8	181.8[b]	7.3	12.6	70.1	82.8[c]	15.3	3.5[e]	9.6
10	12.4	187.8	200.3[b]	10.6	3.4	34.2	37.8[de]	9.1	2.4[e]	6.6
11	18.2	185.0	203.3[b]	13.5	14.9	41.2	54.0[e]	26.6	7.5[e]	20.7
12	3.0	177.4	180.4[b]	2.2	3.6	58.2	61.8[d]	5.8	3.1[e]	8.5
Mean	16.8	177.4	193.7	13.8	30.0	53.4	86.2	33.1	36.4	100.6
SD	13.0	60.0	60.4		21.9	17.8	28.2		36.3	
SEM	1.3	6.1	6.1		2.2	18.1	2.8		3.8	
Probability of differences between farms.			< 0.01				< 0.01		< 0.01	
Recommended Levels[3]										
Min.			121.75				40.2		36.2	
Max.							80.4		804.0	

[1]Percentage of total Ca requirement (121.75 g Ca d^{-1}) that comes from water.
[2]Percentage of Total S intake that comes from water.
[3]1989 NRC Requirements assuming 20.1 kg DMI, 500 kg cow @ 31.7kg 4% milk.

142.9 g Ca d^{-1} (farm 6).

The average amount of Ca obtained from the feed was 177.4 g d^{-1}. This average amount from the feed would supply more than the average cow's daily Ca requirement. Dairy producers appear to be formulating to provide the cows full Ca requirement from the feed. They also seem to be formulating for the highest producing cow. By providing an average of 177 g Ca d^{-1} the producer is supplying adequate Ca for a 500 kg cow producing 48 kg 4% FCM d^{-1} (NRC 1989).

The amount of Ca obtained from the water varied from a low of 1.4 g d^{-1} to a high of 45.4 g d^{-1}. The Ca from the water can account for 1.2% to 37.2% of the cow's daily Ca requirement (121.75 g d^{-1}). On average Ca from the water accounted for 16.8 g d^{-1} or 13.8% of the cow's requirement. Thus it would appear that the producers were ignoring the contribution of water Ca to the cow's Ca intake. This, however, may not cause a problem since none of the producers whose water was high in Ca reported problems with milk fever.

5.2.5.2 Sulfur

Sulfur intake has been divided into intake from water, feed and the total intake (Table 5.14). Average total S intake was 86.2 g d^{-1} which is similar to the maximum recommended S intake of 80.4 g d^{-1}. Four farms (4, 5, 6 and 8) had total S levels of over 100 g d^{-1}. On most farms the major source of S was the feed. However, on five farms (2, 3, 4, 7 and 8) cows received over 47% of their total S intake from the water.

The amount of S that cows receive from the water supply varies from farm to farm depending on the sulfate level of the water and the cow's water intake. This calculated estimate is presented as Water S and shows that, on average, cows received 33.1% of their total S intake from sulfate in the water. This percentage varied from a high of 62.8% to a low of 5.8%. The amount of S that the cows can receive from the water exceeded their requirements on four of the 12 farms. In contrast, Feed S exceeded the cows' requirements on nine of the 12 farms.

Total S intake was found to be significantly correlated to DMI, and the intakes of Cu, Mo, Zn and Fe (Table 5.13). There was no significant correlation between S intake and 4% FCM production. As with other mineral intakes the correlations between S intake and other mineral intakes was at least partially due to the correlation between the mineral intakes and DMI.

The lack of correlation between S intake and 4% FCM production could be due to many factors. One is that a portion of the total S intake is from water. Since the intake of water (and thus S) was estimated using milk production as part of the estimate there is confounding between the two parameters which may obscure any correlation.

Another reason for the lack of correlation between S intake and 4% FCM production may be the level of Mo in the diet. Research with sheep suggests that the poor performance associated with high S diets can be partially alleviated by feeding Mo

(Goodrich and Tillman 1966). In this survey the cow's Mo intake could reduce the effects of a high S diet and a lack of correlation between S intake and milk production could exist.

The lack of correlation between S intake and production could also be the result of variation between herds as to S intake and milk production as evidenced by the significant differences between farm as to these parameters. This means that farms where cows received high levels of S did not necessarily produce higher or lower than average. The differences in milk production on different farms is probably more dependant on overall nutrition and management than it is strictly on S (or any other mineral) intake. Evaluation of the effect of S or Mo or Cu and their interactions on milk production would be more accurate with a designed experiment than in a survey.

The effect of S intake on 4% FCM production, days to 1st heat, days to 1st service, days open, services per conception, plasma Cu and plasma Zn were also tested using linear/quadratic regression analysis. No significant effect was found between these parameters and S intake.

In this survey there was no significant correlation between S intake and Plasma Cu (Table 5.13). One would expect a negative correlation between these two parameters since the level of S which the cows obtained in the survey is as high or higher than the levels found to decrease blood Cu on an experimental basis with cattle (Bingley et al. 1975, Lesperance et al. 1985, Wittenberg and Boila 1987).

In this survey S intake was not significantly correlated to the reproductive parameters Days Open and Services per conception (Table 5.16). This is not unexpected as the effect of S intake on reproduction has not been studied except as it relates to Cu status.

Total S intake was also found to be positively correlated to serum K ($r = 0.29$, $P < 0.01$), glucose ($r = 0.37$, $P < 0.01$) and CPK ($r = 0.34$, $P < 0.01$). S intake was negatively correlated to serum urea ($r = -0.54$, $P < 0.01$). No significant correlations were found between total S intake and serum Na, Cl, P, Mg, total protein, creatinine, A-G ratio, total bilirubin, AP, AST, GGT, and albumin.

5.2.5.3 Sodium

The amount of sodium (Na) that the cows received from the water (feed was not tested for Na), on average, equalled the minimum recommended level of 36.2 g d^{-1} (Table 5.14). The level of Na that cows received from the water varied from a high of 104.3 g d^{-1} to a low of 2.4 g d^{-1}. Thus on farms with water containing high levels of Na cows may be over-supplemented with Na if the amount of Na received from the water is not taken into consideration when formulating rations.

For example, cows will receive Na in the diet a suggested level of 1% salt (NaCl) in the concentrate to enhance palatability (Foley et al. 1972). The level of Na in common feedstuffs varies from 0.11% in alfalfa hay to 0.03% in barley grain (NRC 1989). It is suggested that the complete ration contain 0.5% added NaCl (ibid.). This would provide 39.1 g Na per day (500 kg cow, 31.7 kg 4%FCM yield eating 20 kg DMI d^{-1}) which is greater that the minimum recommended amount of 36.2 g d^{-1} (NRC 1989).

5.2.5.4 Phosphorus

The phosphorus intakes found on farms in this survey were higher than the requirement of 76.8 g d^{-1} with an average of 102.1 g d^{-1} (Table 5.15). Three farms (2, 7 and 11) provided P at below the recommended levels.

The Ca:P ratios provided to the cows as a result of the high Ca intakes are also, on average, above the recommended 1.5:1. Most farms provided, on average, up to 2:1 Ca:P with one farm (11) providing a 3:1 ratio of Ca:P. Very high Ca:P ratios may not cause a problem as long as P intake is adequate (NRC 1989). This is not the case on three of the 12 farms which were providing low P levels. Inadequate P and high Ca:P ratio may lead to decreased feed intake and feed efficiency thus a decrease in milk production as well as anestrus and low conception rates (NRC 1989).

5.2.5.5 Copper

Farm average copper intake was 722.5 mg d^{-1} which is higher than the 201 mg d^{-1} recommended minimum and below the 2010 mg d^{-1} maximum recommended level (Table 5.15). Only two farms (2 and 7)

Table 5.15: Farm Average Cow Phosphorus, Copper, Zinc, Iron and Molybdenum Intake

Farm Number	Phosphorus g d⁻¹	Copper	Zinc	Iron	Molybdenum
		mg d⁻¹			
1	111.9[b]	722.5[c]	2716.6[b]	8606.8[ab]	10.0[bcd]
2	60.5[cd]	110.2[f]	633.4[f]	1875.7[h]	6.2[cd]
3	87.1[bcd]	277.3[def]	1399.6[de]	3437.4[fg]	8.8[bcd]
4	108.5[b]	1128.7[b]	1842.8[cd]	6663.6[cd]	2.7[d]
5	176.1[a]	853.5[c]	3276.7[a]	9044.4[a]	18.8[ab]
6	159.2[a]	1519.1[a]	3729.6[a]	8927.8[a]	15.2[abc]
7	49.6[d]	180.0[ef]	824.9[f]	2589.6[gh]	6.0[cd]
8	99.6[bc]	344.6[de]	1614.0[cd]	4188.0[ef]	13.8[bc]
9	83.4[bcd]	279.8[def]	2155.2[c]	7138.8[bcd]	8.7[bcd]
10	105.0[b]	214.4[def]	1610.7[cd]	5661.1[de]	2.1[d]
11	64.2[cd]	409.3[d]	1036.7[ef]	3522.1[fg]	6.5[cd]
12	98.1[bc]	311.3[def]	1423.3[de]	7768.9[abc]	24.9[a]
Mean	102.1	722.5	2716.6	8606.8	10.1
SD	39.4	417.6	946.6	2600.4	8.0
SEM	3.9	42.4	96.1	264.0	0.8
Probability of differences between farms	<0.01	< 0.01	< 0.01	< 0.01	< 0.01
Recommended Levels[3]					
Min.	76.8	201	804	1005	?
Max.		2010	20100	20100	201

[1]Percentage of total Ca requirement (121.75 g Ca d^{-1}) that comes from water.
[2]Percentage of Total S intake that comes from water.
[3]1989 NRC Requirements in mg d^{-1} assuming 20.1 kg DMI, 500 kg cow @ 31.7 kg 4% milk.

failed to provide the recommended minimum level of Cu. These two farms may not have problems with Cu deficiency even when feeding low levels of Cu since the cows are also receiving relatively low levels of S (61.0 and 61.8 g S d^{-1} respectively, Table 5.14).

Cu intake and 4% FCM production were found to be significantly correlated ($r = 0.20$, $P < 0.05$, Table 5.16). However this could be a result of DMI also being correlated to 4% FCM production and Cu intake (Table 5.13).

There were significant differences ($P < 0.01$) between farms in average Cu intake by cows.

5.2.5.6 Molybdenum

The mean Mo intake of cows in this survey was 10.1 mg d^{-1} (Table 5.15) which is equivalent to approximately 0.5 mg kg^{-1} DM. This level of Mo is low when compared to the recommended maximum level of 201 mg d^{-1} (NRC 1989) but higher than the 1 to 2 mg kg^{-1} DM level suggested to interfere with Cu utilization (Underwood 1981).

There were significant differences ($P < 0.01$) between farms as to the Mo intake of cows (Table 5.15). Individual cow Mo intakes ranged from 2.1 to 24.9 mg d^{-1}.

Mo intake was found to be positively correlated with 4% FCM production, DMI, Zinc intake, Iron intake, and Blood Cu (Table 5.13). The correlation between Mo intake and Zn and Fe intakes are explained by the positive correlations between these parameters and DMI. Thus when DMI increases with milk production

Table 5.16: Correlations of Reproductive Parameters and Selected Blood Parameters

	4% FCM (kg d^{-1})	Plasma Copper	Copper Intake	Plasma Zinc	Zinc Intake	Sulfur Intake	#Services Conception
Plasma Copper	-						
Copper Intake	* 0.20	-					
Plasma Zinc	-	-	-				
Zinc Intake	* 0.25	-	**0.79	-			
Sulfur Intake	-	-	**0.64	-	**0.65		
#Service per Conception	-	* 0.30	-	-	-	-	
Days Open	-	-	-	-	-	-	**0.74

* $P < 0.05$ - not significant

** $P < 0.01$

one would expect corresponding increased intake of Cu, S, Mo, Zn and Fe.

The positive correlation between Mo intake and blood Cu fits the theory of interactions between Mo and Cu in the ruminant. Mills (1980) states that at Mo intake of less than 10 mg kg^{-1} DM Mo and Cu bind both in the rumen and in the tissue to become a biologically inactive complex. In the blood this stimulates the withdrawal of Cu from storage and increases the overall Cu content of the blood (some of which is the inactive Cu-Mo complex) (Dick 1954, Lesperance et al. 1985).

5.2.5.7 Cu to Mo Ratio

A Cu:Mo ratio of less than 2:1 can result in conditioned Cu deficiency in cattle (Miltmore and Mason 1971). None of the 12 farms in the survey had Cu:Mo ratios of less than 2:1. The lowest Cu:Mo ratio was on farm 12 with a ratio of 12.5:1. Therefore it is unlikely that Cu deficiency due to Cu:Mo ratios would appear.

5.2.5.8 Zinc

Zinc intake followed the same pattern as Cu intake (Table 5.15) with those farms having low Cu intakes also having low Zinc intakes. Only one farm (farm 2) provided Zn at a level below the recommended minimum of 804 mg d^{-1}. Two farms (5 and 6) provided Zn to their cows at levels greater than 3000 mg d^{-1}.

Few experiments have studied the effect of high Zn intakes on Cu absorption/status of ruminants. One experiment (Towers et al. 1981) reports a decline in plasma Cu in beef cows and calves receiving 12 to 15 mg $Zn^{-1}kg^{-1}$ body weight. For a 400 kg beef cow this would be equivalent to 4800 to 6000 mg Zn d^{-1}. Since the levels of Zn found in Survey Two are lower than the levels in the Towers et al. (1981) experiment one would not expect to find a direct effect of Zn intake on blood Cu. In this survey there was no significant correlation between Zn intake and blood Cu.

A complicating factor in drawing this conclusion is that the S intakes of cows in this study was high (Table 5.14). It has been observed that high S diets (13.8 g S d^{-1}) resulted in decreased digestive tract solubility of both Cu and Zn (Golfman and Boila 1988). Thus, while the levels of Zn found in this survey may not directly affect the Cu status of the animals, the high S found in many of the cow's diets may reduce the solubility of both Cu and Zn in the digestive tract and make it less available to the animal.

5.2.5.9 Iron

High levels of iron in the feeds were found on most farms (Table 5.15). This resulted in the average cow intake of Fe to be 8,606.8 mg d^{-1} which is almost eight times higher than the 1,005 mg d^{-1} minimum recommendation but lower than the 20,100 mg d^{-1} maximum recommendation (NRC 1989). All farms exceeded the recommended minimum Fe intake in the feed.

The effect of excessive Fe intake on dairy cows has not been extensively studied. One experiment (Coup and Campbell 1964) found that milk production and feed digestibility was significantly reduced when cows were fed even the lowest dose (in that particular experiment) of 15,000 mg Fe d^{-1}. When a even lower level of Fe (4,200 mg Fe d^{-1}) is fed to growing heifers a reduction in liver and plasma Cu can occur (Phillippo et al. 1982). Therefore, while the levels of Fe found in this survey may not be high enough to cause a significant effect on milk production or blood Cu levels it may contribute to the lowering of blood Cu.

Fe intake was found to be significantly correlated to 4% FCM production, DMI, Cu intake, S intake, Mo intake and Zn intake (Table 5.13). The positive correlation with 4% FCM production could be partially due to Zn being positively correlated with DMI and DMI being positively correlated with 4% FCM production.

Iron in the water was not analyzed for two reasons: 1) none of the farms complained of excessive iron in the water and little staining of fixtures was evident. 2) iron levels in the water are usually between 1 and 5 mg l^{-1} and thus do not contribute greatly to the iron content of the diet especially compared to the iron content found in the feed.

5.2.6 Blood Analysis

5.2.6.0 Introduction

Farm average blood analysis results are presented in Tables 5.17a and 5.17b along with overall averages and normal values. These blood analyses were from a small number of early lactation cows within each herd which were only blood sampled once. Therefore no correlations between various blood parameters and stage of lactation were calculated. For such correlations to be valid, cows should be tested at regular intervals during a lactation as reported by Parker and Blowey (1976) and Rowlands et al. (1975).

Unless otherwise stated all herd averages fell within the normal ranges included with each blood analysis. In many cases of abnormal results logical explanations are not available.

Simple correlations were calculated on selected blood parameters. Significant or lack of correlations between various parameters many times defied a logical explanation. As with all correlation analysis a significant correlation between two parameters does not necessarily imply a cause and effect relationship (Little and Hills 1978). Also, lack of correlation does not necessarily mean lack of relation as the relationship between the two variables may be curvilinear (Little and Hills 1978). One contributing factor to some of the unexpected results is the fact that only one blood sample was taken from each cow.

5.2.6.1 Plasma Copper

The plasma Cu concentrations in this survey were almost all within the normal range of 9.4 to 23.6 $\mu mol\ l^{-1}$ (Underwood 1981) (Table 5.17a). However most were at the low end of the normal range. One herd (farm 7) had a herd average plasma Cu of 9.0 $\mu mol\ l^{-1}$. On this farm the plasma Cu levels ranged from 7.0 to 12.8 $\mu mol\ l^{-1}$ which may indicate marginal a Cu status (Underwood 1981). The average Cu intake on this farm (Table 5.15) was 180 mg d^{-1} (15 mg kg^{-1} DM) (ave. DMI of 11.9 kg d^{-1} - Table 5.12). While this concentration of Cu is above the recommended 10 mg kg^{-1} DM (NRC 1989) this farm's water supply contained 1060 mg l^{-1} of sulfate resulting in an average total S intake of 61.8 g S d^{-1}. This level of intake is greater than the 40.2 g S d^{-1} minimum requirement (NRC 1989) and thus the excess S could complex with the Cu making it unavailable resulting in a lower level of available Cu in the diet (Suttle and Peter 1985).

Plasma Cu was found to be significantly correlated to Molybdenum intake (Table 5.13), Days in Milk (Table 5.10) and Services per Conception (Table 5.16). The correlation with Molybdenum intake is discussed in section 5.2.5.5. The correlation between plasma Cu and Days in Milk was negative and thus could indicate depletion of Cu stores in late pregnancy and during the production of colostrum. This correlation is comparable to the findings of McMurray (1980) and Kappel et al. (1984) who found that plasma Cu increased sharply in the first two weeks after calving and then gradually decreased. Since the

Table 5.17a: Analysis of Plasma Cu and Zn and Serum Parameters

Farm Number	Cu ($\mu mol\ l^{-1}$)	Zn ($\mu mol\ l^{-1}$)	Na (mmol l^{-1})	K (mmol l^{-1})	Cl (mmol l^{-1})	Ca (mmol l^{-1})	P (mmol l^{-1})	Mg (mmol l^{-1})	Urea (mmol l^{-1})	Creatinine ($\mu mol\ l^{-1}$)
1	12.9	13.9	139.0	4.60	96.0	2.37	2.28	0.94	5.12	93.1
2	12.0	13.1	142.2	4.52	99.6	2.43	2.47	0.93	6.59	95.2
3	12.9	11.8	142.2	4.37	94.6	2.44	1.54	0.98	4.89	109.1
4	12.2	13.4	139.1	5.45	97.4	2.47	1.96	0.90	1.80[1]	110.7
5	12.4	13.4	141.4	4.71	99.5	2.17	2.34	0.83	5.43	83.8
6	11.9	13.2	140.1	4.67	97.2	2.44	1.91	0.85	6.37	73.1
7	9.0	12.6	140.0	4.80	93.2	2.47	1.88	1.02	6.36	86.8
8	13.5	13.9	138.2	5.74	97.2	2.42	1.78	0.91	3.58	99.3
9	14.8	11.2	138.4	4.77	93.7	2.41	1.93	0.92	5.72	95.1
10	12.8	14.1	137.2	4.07	96.8	2.41	1.99	0.70	6.82	104.0
11	11.8	13.5	140.2	5.24	96.5	2.48	2.28	0.97	7.68	78.1
12	16.7	12.9	138.6	4.99	98.3	2.33	2.00	0.80	6.27	99.0
Mean	12.98	13.94	139.9	4.83	96.9	2.39	2.04	0.88	5.41	94.5
SD	3.05	2.63	2.70	0.57	3.26	0.17	0.44	0.13	2.00	15.28
SEM	0.31	0.27	0.27	0.05	0.33	0.01	0.04	0.01	0.20	1.55
Normal[3]:										
Min.	9.4[2]	12.2[2]	135	3.9	96	2.11	1.08	0.80	0.00	67
Max.	23.6[2]	18.3[2]	151	5.9	110	2.75	2.76	1.32	7.5	175

1On this farm 6 out of 7 cow's blood urea was reported as <1.8 mmol l^{-1}. The other cow's blood urea was 1.9 mmol l^{-1}.
2Underwood 1981
3Normal ranges as published with blood test results from WCVM 1988.

data in this survey included few cows less than 14 Days in Milk a negative correlation between plasma Cu and Days in Milk was expected. Plasma Cu was positively correlated with services per conception. One would expect little correlation between these two parameters since cows were only blood sampled once. Conclusions as to the effect of plasma Cu concentration on reproductive and productive parameters are more reliable when cows are blood sampled at regular intervals during the lactation. In one such case Kappel et al. (1984) found no significant differences in plasma Cu between cows grouped by Days Open. In this study at the time of the first service (averaging 70 Days in Milk) there were no significant differences in plasma Cu between groups. The reason for this small negative correlation with services per conception in this survey is unexplained but may be related to the small number of cows with complete records of services per conception.

5.2.6.2 Plasma Zinc

The mean plasma Zn concentration found in this survey was 13.94 $\mu mol\ l^{-1}$ (Table 5.17a). All but two farms (3 and 9) had average plasma Zn levels within the normal range of 12.2 to 18.3 $\mu mol\ l^{-1}$ (Underwood 1981). On the farms with the lowest average plasma Zn concentration (farm 9) cows received an average of 2155.2 mg Zn d^{-1} (Table 5.15) which is equivalent to approximately 112 mg kg^{-1} DM (ave. DMI of 19.2 kg d^{-1} - Table 5.12). This level of intake is almost three times the 40 mg kg^{-1}

DM minimum recommended level (NRC 1989). The reason for the low plasma Zn on this farms in unknown. A conclusion of Zn deficiency can not be made unless two consecutive low plasma Zn concentrations are found on two separate occasions (Subcommittee on Zinc 1979).

Zinc absorption and retention by ruminants has been found to decrease on low protein diets (Subcommittee on Zinc 1979). This may be the cause of the low plasma Zn on farm 3 as the protein intake was averaged less than the requirement (Table 5.12). On farm 9 the amount of protein provided for the cows was, on average, more than adequate (Table 5.12). However, this protein may not have had a sufficient level of solubility to provide an adequate level of usable (soluble) protein. Thus these cows may also be receiving a low (soluble) protein diet.

Plasma Zn was found to be significantly correlated to serum albumin-globulin ratio (A-G ratio) and serum albumin (Table 5.18). The major function of albumin is as a general binding, storage and transport protein (Kaneko 1980). Albumin, along with zinc-α_2-macroglobulin are the major transport proteins for Zn in the blood (Subcommittee on Zinc 1979). Thus it is not surprising that plasma Zn and serum albumin (and thus A-G ratio) were found to be significantly correlated.

Plasma Zn was also found to be not correlated to SCC and alkaline phosphatase (AP) (Table 5.18). One could expect plasma Zn to fall in response to infection (Subcommittee on Zinc 1979) thus it should be negatively correlated to SCC since high SCC

Table 5.18: Correlations of Selected Nutrients and Milk Somatic Cell Count and Selected Blood Parameters

	Dry Matter Intake	Protein Intake	SCC	Serum Urea	Serum Protein	Serum Creat.	Serum Glucose	Serum A-G ratio	Plasma Zinc	Serum Alk.Phos.	Serum Albumin
Protein Intake	** 0.90										
Somatic Cell Count (SCC)	-	-									
Serum Urea	-	-	-								
Serum Total Protein	-	-	-	**0.27							
Serum Creatinine	* -0.22	**-0.33	-	**-0.34	-						
Serum Glucose	**0.40	**0.36	-	-	-	-					
Serum Albumin-Globulin Ratio	-	-	-	-	**-0.54	* 0.21	-				
Plasma Zinc	-	-	-	-	-	-	-	**0.32			
Serum Alkaline Phosphatase	-	-	* 0.29	-	-	-	-	-	-		
Serum Albumin	-	-	-	* 0.19	-	-	-	**0.72	**0.51	* -0.23	
Serum CPK	-	-	-	-	-	-	* 0.22	-	-	-	-

* $P < 0.05$
** $P < 0.01$

\- not significant

indicates mastitis. However in this survey the two cows with clinical mastitis and thus SCC of greater than one million did not have lower plasma Zn levels than their herd average. Also the relationship between plasma Zn and mastitis in dairy cows has not been studied. One could theorize that in cases of mastitis where there is no accompanying systemic infection there may not be a lowered plasma Zn.

The relationship between AP and Zn deficiency has been studied (Subcommittee on Zinc 1979). In young pigs the enzyme was consistently reduced in Zn deficiency (Norrdin et al. 1973) however, there was little change in AP activity in young Zn deficient calves (Subcommittee on Zinc 1979). The relationship between AP and Zn status is not as strong in older animals thus it is not surprising that no correlation was found to exist between these two parameters (Table 5.18). Also, AP activity can be altered by conditions other than Zn deficiency which interfere with normal liver and bone metabolism (Subcommittee on Zinc 1979).

5.2.6.3 Serum Sodium

Little variation was found between cows in their serum sodium (Na) levels (Table 5.17a). This was expected as other researchers (Jaster et al. 1978) found no significant effect of high NaCl water (2500 mg l^{-1} NaCl) on the serum Na content of milking cows. Also, Kaneko (1980) states that serum Na levels show a very wide range in cattle and are therefore of little diagnostic value. The Na content of serum was found to be significantly increased when growing heifers were supplied with water containing 17,500 mg l^{-1} NaCl (Weeth and Haverland 1961) or 15,000 mg l^{-1} NaCl (Weeth and Lesperance 1965).

5.2.6.4 Serum Potassium and Chloride

Farm mean serum potassium (K) and chloride (Cl) were all within normal ranges in this survey. Two farms (4 and 8) had unexplained slightly elevated serum K concentrations. These elevated concentrations were consistent for all cows tested in these herds.

5.2.6.5 Serum Calcium, Phosphorus and Magnesium

Serum levels of calcium (Ca), phosphorus (P) and magnesium (Mg) were all within expected normal ranges (Table 5.17a). These results were expected since plasma concentrations of Ca and P are highly regulated in mammalian species (Guyton 1981).

5.2.6.6 Serum Urea

The serum urea concentrations of cows in this survey were, on average, within the normal range of 0 to 7.5 mmol l^{-1} (Table 5.17a). However, the normal range obtained with the blood test results from WCVM is in disagreement with those of Kaneko (1980) who reports that the normal range of blood urea-N for a cow is 7.1 to 10.7 mmol l^{-1}. If the normal range reported by Kaneko (1980) is used then only one farm (farm 11) had an average serum urea value within the normal range. All the other farm averages were below this range with one farm (farm 4) having very low serum urea values. While there is a disagreement as to what the normal range of serum urea-N is it would appear from this survey that the normal range for dairy cows in early lactation is from 3.0 to 8.0 mmol l^{-1}.

The cows on the farm with the highest serum urea (farm 11) all had serum urea values greater than 7.1 mmol l^{-1}. High serum urea can be indicative of accelerated protein catabolism (Kaneko 1980) or of feeding excessive levels of protein that is degradable in the rumen (Ferguson et al. 1988).

The unusual serum urea values found on these farms may have been due to the cows diets, however, the effect of diet on serum urea is complex (Kaneko 1980). Several researchers have studied the effects of high/low, degradable/undegradable protein on dairy cows (Ferguson et al. 1986, Ferguson et al. 1988, Blauwiekel and Kincaid 1986). All of these researchers found that increasing the protein content of the diets resulting in increased serum urea. The serum urea concentration could be increased even further by providing a diet with higher levels of rumen-degradable protein (Ferguson et al. 1986, Ferguson et al. 1988).

The farm with the highest average serum urea (farm 11) had adequate protein and TDN intake (Table 5.12) while the farm with low serum urea (farm 4) had less than adequate protein intake. It is possible that the farm with the high serum urea values was feeding a diet containing a high percentage of degradable protein.

In this survey no correlation was found between serum urea and protein intake, dry matter intake or any of the reproductive parameters. (Table 5.18). One could expect a correlation between serum urea and days open as other researchers (Ferguson et al. 1986, Ferguson et al. 1988, Blauwiekel and Kincaid 1986) have found that cows exhibiting fertility problems also had high serum urea concentrations due to excessive levels of rumen-degradable protein in the ration.

Serum urea was found to be positively correlated to serum total protein and serum albumin and negatively correlated to serum creatinine.

5.2.6.7 Serum Creatinine

Creatinine is the end product of phosphocreatine degradation to provide energy to muscles (Kaneko 1980). Serum creatinine will rise in response to muscle damage, tissue wasting or physical training.

The serum creatinine values obtained from the cows in this survey all fell within the normal range of 67 to 175 $\mu mol\ l^{-1}$ (Table 5.17a). This was expected as creatinine levels in the blood are fairly stable (Kaneko 1980).

Serum creatinine was found to be negatively correlated with both dry matter and protein intake (Table 5.18). As dry matter and protein intake decrease the animal will draw on muscle tissue for its protein and energy needs. This will result in tissue wasting and thus creatinine will rise (Kaneko 1980).

Other correlations were found to exist between serum creatinine and serum urea and A-G ratio however, these correlations remain unexplained (Table 5.18).

5.2.6.8 Serum Glucose

The mean serum glucose value was within the 1.8 to 3.9 mmol l^{-1} normal range as were the means of most of the farms (Table 5.17b). One farm (farm 5) averaged higher than the normal maximum serum glucose value with a mean of 4.22 mmol l^{-1} and all cows tested having serum glucose values of greater than 3.8 mmol l^{-1}. This farm provided more than adequate levels of TDN and DMI to their cows (Table 5.12) and provided grain via a computer feeder (Table 5.4). This may have kept these cows in a positive energy balance and thus elevated their serum glucose values. Another explanation for this herd's high serum glucose values could be that the cows were blood sampled during the daily peak in blood glucose. Serum glucose was found to be significantly correlated to dry matter and protein intake and to serum creatine phosphokinase (CPK) (Table 5.18). While the correlation between feed intake and blood glucose values is thought to be less strong in ruminants than non-ruminants the relationship still remains (Kaneko 1980). In this survey, increased DM and protein intake would provide more energy to the animal and thus blood glucose levels could rise. The positive correlation between serum glucose and serum CPK is unexplained.

Table 5.17b: Analysis of Serum Parameters (continued)

Farm Number	Glucose mmol l^{-1}	Total Bilirubin $\mu mol\ l^{-1}$	Alkaline Phosphatase U l^{-1}	CPK U l^{-1}	AST U l^{-1}	GGT U l^{-1}	Total Protein g l^{-1}	Albumin g l^{-1}	A-G ratio
1	3.65	0.00	36.1	159.5	66.3	19.7	70.2	33.0	0.79
2	3.30	0.40	40.6	83.2	60.4	28.1	78.7	36.1	0.88
3	3.68	0.00	67.9	163.4	79.7	27.6	74.2	32.2	0.78
4	3.20	0.28	42.0	290.2	76.0	23.1	70.5	35.0	1.05
5	4.22	0.00	35.7	563.9	72.1	27.2	75.3	35.7	0.92
6	3.21	0.42	44.0	109.0	72.0	24.0	76.6	34.1	0.82
7	2.96	0.00	41.6	145.6	77.8	21.4	72.4	36.4	1.01
8	3.31	0.00	41.3	437.1	72.3	26.5	79.3	35.4	0.83
9	2.97	0.00	44.4	198.1	74.7	26.2	79.4	30.4	0.62
10	3.17	0.00	43.0	118.4	75.0	19.8	75.8	37.8	1.01
11	2.88	0.71	41.8	163.4	78.8	21.2	82.5	37.0	0.82
12	3.21	0.70	37.2	145.0	84.9	26.7	75.2	35.5	0.92
Mean	3.36	0.21	43.1	223.1	74.0	24.7	75.9	34.8	0.87
SD	0.57	0.75	16.0	304.1	17.7	7.9	8.13	3.1	0.19
SEM	0.05	0.07	1.6	30.8	1.8	0.8	0.82	0.3	0.02
Normal:									
Min.	1.8	0.00	0.0	0.0	46.0	0.0	66.0	23.0	0.66
Max.	3.9	30.00	121.0	350.0	118.0	31.0	78.0	43.0	1.30

5.2.6.9 Serum Bilirubin

The concentrations of serum bilirubin found in this survey were all within the normal range of 0 to 30 $\mu mol\ l^{-1}$ (Table 5.17b). None of the cows with serum bilirubin values above 0 $\mu mol\ l^{-1}$ had levels which would indicate hepatic damage (Kaneko 1980).

5.2.6.10 Serum Alkaline Phosphatase

Alkaline phosphatase (AP) is an important enzyme for characterizing bone disorders (Kaneko 1980). This enzyme could assist in assessing Zn status in animals (Subcommittee on Zinc 1979). However AP is not consistently lowered in cases of clinical Zn deficiency and thus it is of not greater value than plasma Zn in assessing Zn status (Subcommittee on Zinc 1979). In support of this no significant correlation was found between plasma Zn and AP (Table 5.18).

In this survey all AP values were within the normal range of 0 to 121 $U\ l^{-1}$ (Table 5.17b).

5.2.6.11 Serum Creatine Phosphokinase

Creatine phosphokinase (CPK) catalyzes the reversible phosphorylation of creatine in muscle and thus is indicative of muscle stress or damage (Kaneko 1980). CPK has a short half-life is serum and falls quickly after the stress ceases.

In this survey two farms (5 and 8) had average CPK values greater than the 350 $U\ l^{-1}$ normal maximum (Table 5.17b). On farm

5 this was due to two cows with CPK values of greater than 1000 U l^{-1}. On farm 8 one cow had a serum CPK value of greater than 1500 U l^{-1}. The reasons for these high levels in individual cows is not known but could be due to blood sampling stress, recent intermuscular treatment or recent physical trauma.

Correlations between serum CPK and other serum parameters are presented in Table 5.18. Serum CPK was significantly correlated only to serum glucose. The reason for this relationship is not known but may be due to stress and excitement.

5.2.6.12 Serum Aspartate Aminotransferase

Aspartate aminotransferase (AST) is present in the mitochondria and cytosol of almost all cells and in plasma. It, along with serum glutamic oxaloacetate transaminase (GOT) rise more slowly than serum CPK when muscle damage occurs (Kaneko 1980). Since all cows had levels of AST within the normal range of 46 to 118 U l^{-1} (Table 5.17b) the muscle damage indicated by the few high serum CPK values must have been due to short-term damage.

5.2.6.13 Serum Gamma Glutamyltransferase

Gamma glutamyltransferase (GGT) is an enzyme whose physiological significance is unknown, however, it has been found to increase in cases of obstructive liver disease and thus provides an indicator of this condition (Kaneko 1980).

In this survey all cows had levels of serum GGT within the normal range of 0 to 31 U l^{-1} (Table 5.17b).

5.2.6.14 Serum Total Protein/Albumin/Albumin-Globulin Ratio

These three blood parameters are considered together due to their interrelationship in the blood. In automated blood analysis systems values for Total protein and Albumin are used to calculate the Albumin to Globulin ratio (A-G ratio) since total protein will include both albumins and globulins (Kaneko 1980). Thus it is not surprising that serum Total protein and A-G ratio were found to be correlated (Table 5.18).

Herd average levels of serum Albumin and A-G ratio fell within the normal ranges (Table 5.17b). Four farms had serum Total protein concentrations above the normal maximum of 78 g l^{-1}. Simple dehydration can cause an increase in serum Total protein with no change in A-G ratio (Kaneko 1980). It is not known whether these cows were dehydrated though it is possible as blood samples were usually taken just after milking when cows had been denied water for some time while waiting to be milked.

5.3 Conclusions

The average water on farms in Survey Two contained 727.6 mg l^{-1} hardness, 816.4 mg l^{-1} sulfate, 5.9 mg l^{-1} nitrates, 2313.3 $\mu S\ cm^{-1}$ conductivity, 396.3 mg l^{-1} alkalinity, 148.2 mg l^{-1} Ca, 31.6 mg l^{-1} Mg, 320 mg l^{-1} Na and had a pH of 7.3. Farms were chosen to provide a wide range of water sulfate levels and thus water sulfate ranged from 84 mg l^{-1} to 2220 mg l^{-1}.

Average 4% FCM production in Survey Two was 31.7 kg cow-^{1}day^{-1}. Stepwise regression found that 4% FCM production was significantly affected by DMI and Days in Milk (r^2 = 0.28, $P < 0.01$) but not significantly affected by the intakes of protein, nitrates, sulfur, Cu, Zn and Fe. Correlation analysis indicated significant correlations between 4% FCM production and hardness, sulfates, nitrates and Ca levels in the water. Stepwise regression using 4% FCM production and water quality parameters found that nitrates had a negative effects on production (r^2 = 0.14, $P < 0.05$).

This survey indicated that cows could receive from 1.4 to 43% of their Ca requirements from Ca in the water. Cows can also receive from 5.8 to 62.8% of their daily S intake from S in the water. Na in the water can account for 6.6 to 288% of the cow's Na requirement.

Cu status, as measured by plasma Cu content, was found to be correlated to Mo intake, Days in Milk and Services per conception. There was not significant correlation between plasma Cu and Total S intake however, there was significant positive correlation between S intake and serum K, glucose, CPK, and significant negative correlation between S intake and serum urea. Total S intake was not significantly correlated to other serum parameters.

6. RECOMMENDATIONS ON THE EFFECTS OF WATER QUALITY PARAMETERS ON DAIRY PRODUCTION

Hardness, Calcium and Magnesium

Hardness per se has little effect on dairy cattle. However, hardness consists of Ca and Mg. If a water has a high level of hardness I would recommend testing it for the levels of Ca and Mg to determine if the levels make a significant contribution to the animal's diet. The level of Ca in the water can supply the cow with their entire requirement.

Testing the water for Ca content is especially important on farms with unexplained incidences of milk fever.

Sulfates

- Sulfates appear to have little effect on cattle when present in water at levels of less than 1000 mg l^{-1}.

- Sulfates at levels greater than 1000 mg l^{-1} provide the cow with their entire daily requirement for sulfur. Thus feed S levels should be checked to determine the total S intake of the cow.

- At sulfate levels greater than 1000 mg l^{-1} dietary levels of Cu, Zn, Fe and Mo should be checked since S, Zn, Fe and Mo can all interfere with Cu metabolism. Levels of Cu in the ration should be increased from the minimum of 10 mg kg^{-1} DM to as high as 40 mg kg^{-1} DM when S levels in the ration exceed the cow's requirement. As well, some effort should be made to reduce the Fe content of the ration since many rations are high in Fe and high levels of this mineral has been found to affect milk production.

- Water sulfate levels of greater than 3000 mg l^{-1} will cause diarrhea and affect milk production. The producer should find another low sulfate water source for the high producing cows or dilute the water with a low sulfate water source. If the producer must use this water then other stresses on the cows should be reduced as much as possible and other sources of S in the diet should be reduced.

Nitrates

- Be aware of the units used to report "nitrates".

- If the water contains nitrates at levels greater than 10 mg l^{-1} then the source of the nitrates should be found and eliminated. Most nitrates are found in the water of shallow wells (< 30m). If nitrates are found in deeper wells then the well is being contaminated at or near the surface.

- Nitrates at levels greater than 22 mg l^{-1} (nitrates plus nitrites expressed as nitrate-nitrogen) are not acceptable for human consumption and should not be used to mix milk replacer for humans or livestock.

- Nitrates at levels less than 100 mg l^{-1} do not seem (from these surveys) to affect mature dairy cattle, however, the effect of higher levels of nitrates is uncertain.

Conductivity/Salinity/TDS

- There seems to be no effect of TDS in the water on mature dairy cattle, however, there may be substances in the TDS that have an offensive taste and thus reduce cow water intake. Reduced water intake will lead to decreased feed intake and decreased milk production.

pH

- Most waters have a pH of 6 to 8 which is a level acceptable to humans and livestock. Water with a ph outside the normal range should be further tested to find the source to the deviation.

- Both acidic and basic water can have an offensive taste, harm machinery and reduce the efficiency of soaps not designed to work in these waters.

- The pH of water can change with time and should thus be tested as soon as possible after sample collection.

Sodium

- The level of Na in the water should be checked since it was found in Survey Two that cows can receive from 6 to 290% of their daily requirement of Na from the water.

- If the level of Na in the water supplies a significant proportion of the cow's Na requirement then Chloride from a source other than salt (NaCl) should be used in the ration.

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APPENDIX A

Questionnaires used in Survey One

WATER QUALITY QUESTIONNAIRE
TO BE COMPLETED BY DAIRY PRODUCER

NAME________________________________

ADDRESS______________________________

____

PHONE_________________

LAND LOCATION__________________________ RM #__________________

SOURCE OF WATER COWS ARE DRINKING: (Circle appropriate)

Well Dugout Other (please specify)

____

____

If well, what is depth?________ feet.
Type of well: (Circle appropriate)

Large diameter bored (30 inches or more in diameter)

Small diameter drilled

If large diameter bored, is there a clay cap and adequate slope away from the center to prevent runoff entry? Yes or No

DAIRY HERD:

Number of cows milking ______ dry ______ at time water is sampled

Breed type __________________

Herd enrolled in: DHAS, ROP, none (Circle appropriate)

Milk shipped in current pickup ________ kg from how many milkings______

THE FOLLOWING PORTION FOR LAB USE ONLY

Water analysis results:

Total Hardness _____________ mg/l

Sulfates _____________ mg/l

Nitrates _____________ mg/l

Conductivity _____________ µS/cm

WATER QUALITY QUESTIONNAIRE

SECOND SAMPLE OF SAME WATER SOURCE

NAME ______________________________

ADDRESS ______________________________

____

POSTAL CODE ____________ PHONE ____________

LAND LOCATION ___1/4 SEC___ TWN ___ RNG ___ W OF ___ RM# ____

SOURCE OF WATER COWS ARE DRINKING: (circle) WELL

DUGOUT

OTHER, please specify

____

____

Depth of Well: ________ feet

Type of well: Large diameter (30 inches or more)

Small diameter drilled

DAIRY HERD

Number of cows milking _____ dry _____ at time water is sampled

Breed type ______________________________

Herd enrolled in: DHAS ROP NO PERFORMANCE PROGRAM

Current milk shipment: ___________ kg milk

How many times were your cows milked for this pickup ________

THE FOLLOWING PORTION FOR LAB USE ONLY

Water Analysis results:

Total Hardness __________ mg/l
Sulfates __________ mg/l
Nitrates __________ mg/l
Conductivity __________ µS/cm

APPENDIX B

"DataEase" forms used in Survey Two

```
FORM    cows
--------------------------

1        10        20        30        40        50        60        70        80
----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
FARM NAME: ____________   Index: ___     Date: ________

Cow Name: ________       Date of birth: _______    Age:____
                         Lact #:__                 Body wt:_____
Present calv dt: _______     Current d in milk:_____
Last calv dt:    _______
Dt 1st heat:     _______    Days 1st heat:    _____
Dt 1st serv:     _______    Days 1st serv:    _____    D 1st heat code: _____
Dt last serv:    _______    Days open:        _____    D 1st serv code: _____
Dryoff dt:       _______    Days dry:         _____    D open code:     _____
#serv present:   _____                                 Ave serv/concept:____
#serv last:      _____      Calv interval:    _____
Prev dt 1st heat:_______    Prev d 1st heat:  _____
Prev dt 1st serv:_______    Prev d 1st serv:  _____
Prev dt last sv: _______    Prev days open:   _____
BLOOD
Sodium mmol/l:       ___
Potassium mmol/l:    _____
Chloride mmol/l:     ___
CO2 mmol/l:          ___
Anion gap mmol/l:    ___
Calcium mmol/l:      _____
Phosphorus mmol/l:   _____
Magnesium mmol/l:    _____
Urea mmol/l:         _____
Creatinine umol/l:   ___
Glucose mmol/l:      _____
T Bilirubin umol/l:_____
Alk Phos U/l:        ___
CPK U/l:             _____
AST U/l:             ___
GGT U/l:             ___
T Protein g/l:       ___
Albumin g/l:         ___
A/G ratio:           _____
Copper ppm:          ____     Copper umol/l: ____
Zinc ppm:            ____     Zinc umol/l:   ____


MILK                Date:________
SCC:              _________
% Fat:            ____
% Prot:           ____
Prod/d (kg):      ____     4% prod/d:____
Proj prod/yr:_____
BCA fat:          ____
BCA milk:         ____
----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
1        10        20        30        40        50        60        70        80
```

```
FORM   feeds
---------------------------

1        10        20        30        40        50        60        70        80
----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
FARM NAME: _______________ Index:___      Date:________

Cow Name:  _______________    Milk prod (kg/d):_______ Body wt:____
Feed type: _______________ kg/cow/d: _____         Moisture (%): ____
                                     DM Intake (kg/cow/d): _______
Values as reported: 90% DM           DMI as % BWt:____
Protein (%):          _____                Protein (kg/d):  _______
TDN (%):              ___       100% DM    TDN (kg/d):      _______
Calcium (%):          ______  g/kg DM:_______  Total Ca (g/d):  _______
Phosphorus (%):       ______  g/kg DM:_______  Total P (g/d):   _______
Nitrate (% K-NO3):_____  mg K-NO3/kg DM:_______  Total NO3 (mg/d):_______
pH : ______                                Total NO3-N (mg/d):_______
Copper (ppm):         _________ mg/kg DM:_______  Total Cu (mg/d): _______
Sulfur (%):           ______  mg/kg DM:_______  Total S (mg/d):  _______
Molybdenum (ppm):     ______  mg/kg DM:_______  Total Zn (mg/d): _______
Zinc (ppm):           _________mg/kg DM:_______  Total Fe (mg/d): _______
Chloride (%):         ______  mg/kg DM:_______  Total Mo (mg/d): ______
Iron (ppm):           _________mg/kg DM:_______

----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
1        10        20        30        40        50        60        70        80
```

```
FORM   water
---------------------------

1         10        20        30        40        50        60        70        80
----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
FARM NAME: _______________ Index:___         Date:________

Cow Name:  _______________    Milk prod (kg/d):_______ Body wt:____

WATER                   Well depth (m): _____        l/cow/d: _____

Hardness (mg/l):            _____
Sulfates (mg/l):            _____       mg S/d:  _______
Nitrates (mg NO3-N/l):_____             mg NO3/d:______
Conductivity (uS/cm): _____             mg NO3-N/d:_______
pH: _____
Alkalinity (mg/l):          _____
Calcium (mg/l):             _____       g Ca/d:  ____
Magnesium (mg/l):           _____
Sodium (mg/l):              _____       mg Na/d: _______
----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
1         10        20        30        40        50        60        70        80
```

APPENDIX C

The effect of changing the water pH
on farm 1 on the stepwise regression.

Farm 1

When the pH of the water was first tested it was 3.1. One year later it was 7.9.

Stepwise regression analysis

1) With farm 1 pH = 3.1 (as in section 5.2.1.3)

Equation:

$$\text{Conductivity} = 2214.8 + (1.2 \times SO_4) - (3.5 \times NO_3) + (2.08 \times Na) - (229.5 \times pH)$$

Examples:

Farm 1 - Measured Conductivity = 3760 $\mu S\ cm^{-1}$
Calculated Conductivity = 3742 $\mu S\ cm^{-1}$

Farm 3 - Measured Conductivity = 2460 $\mu S\ cm^{-1}$
Calculated Conductivity = 2041 $\mu S\ cm^{-1}$

2) With farm 1 pH = 7.9

Equation:

$$\text{Conductivity} = -741.6 + (0.40 \times SO_4) + (3.61 \times Ca) + (3.34 \times Na)$$

Examples:

Farm 1 - Measured Conductivity = 3760 $\mu S\ cm^{-1}$
Calculated Conductivity = 2387 $\mu S\ cm^{-1}$

Farm 3 - Measured Conductivity = 2460 $\mu S\ cm^{-1}$
Calculated Conductivity = 1059 $\mu S\ cm^{-1}$