Linking Groundwater Quality to Soil Properties, Landscape Characteristics and Farm Practice
A Spatial Analysis of the 'Groundwater Characterization in R.M. of Leroy' dataset

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Key Words: groundwater, nitrogen, soil properties, well contamination, phosphorus, farm practice

Abstract

The objectives of this study are to determine the source and extent of nitrogen and phosphorus contamination in the Rural Municipality of Leroy, and the most likely modes of contaminant transport, using only existing data. The analysis was conducted without the benefit of further data collection. Data types include information about well properties, land use, farm management practices and selected water quality parameters, obtained from the original Leroy well water study ('Groundwater Characterization in RM of Leroy', March 2001.) Soils databases, Canadian census information, topographic data and hydrographic data were also drawn upon to analyze water quality data in a GIS environment.

Nitrate levels in the wells in the RM of Leroy are high. The mean nitrate concentration of (15.6 mg/L) is higher than the Health Canada guideline. This result is in part due to the effect of a few very high values. This analysis revealed a clustering of contaminated wells in three general areas of the RM. Nitrate contamination is largely associated with shallow, large diameter wells. Deep wells show much lower levels of nitrate. Six wells had nitrate levels above 100 mg/L and one well was above 200 mg/L. However, 25 percent of all the wells would be considered unfit for human consumption. Nitrogen sources are almost certainly from point-source, agricultural activities and this study points to the likelihood that most nitrate contamination is resulting from activities that occur close to the wells. Nitrate contaminated wells are in close proximity to surface water bodies and also associated with coarse textured soils and soils that have identifiable deposits of sand and gravel. Sand and gravel may provide preferred pathways for flow of contaminants from the surface to shallow groundwater as well as function as conduits for high flow rates within an aquifer. There is little evidence of widespread, non-point source contamination. No clear association with annual cropping in general is apparent. However, the predominance of farming as a land use in the municipality prevents any comparison with other land uses. Livestock operations are an identified source of nitrate. Contaminated wells are significantly associated with animal corrals. Other farm yard factors appear to contribute to nitrate pollution in some cases. These include septic fields and proximity to cropland that has received treatments of either manure or synthetic nitrogen fertilizers. A statistically insignificant ($p=0.15$) but suggestive finding was a relationship between nitrate levels and proximity to intensive livestock operations. Intensive animal facilities are a relatively new development in the mix of agricultural operations in the RM so it is difficult to draw a conclusion from this result. There may have been an impact of applied manure on shallow groundwater already or the

finding may be coincidental. However, in view of the suggestion that leaching may take a great many years to occur, high levels of manure production and application to cropland may represent an impact to shallow groundwater that will not be realized for a long time. There is an indication that nitrate contamination is associated with timber cribbing. However, this study is not able to isolate the possible role that deteriorating wood may play in raising nitrate levels.

Phosphorus levels in the wells varied widely but this analysis was unable to discover underlying factors that might explain this variability.

Introduction

Many water wells in rural areas provide poor quality water. Although naturally occurring dissolved minerals are commonly the cause of poor quality, groundwater sources are frequently impaired by point and non-point source pollution. Contaminants which have negative effects on human health are of primary concern. The most common contaminants causing health problems are bacteria and nitrates. *E. Coli* contamination of drinking water may cause illness and death in human hosts. Reduction of ingested nitrate to nitrite in the gastro-intestinal tracts of infants and immune-compromised individuals may cause serious health problems by blocking the oxygen binding capacity of blood (Jasa et al., 1998). In babies, this condition is known as methemoglobinemia or "blue baby syndrome". High nitrate levels in water and forage can also be fatal to ruminant animals through the same mechanism (Kott, 1998).

The correlation between human activities and groundwater pollution has been well documented. Numerous studies have shown that agricultural activities and the management of domestic wastes on farms can cause the deterioration of water quality. Although background levels of nitrate vary from region to region, naturally occurring concentrations in groundwater are generally lower than the health guidelines. In the US, concentrations over 3 mg/L nitrate-N are attributed to human activity (Madison, and Brunett, 1984). High levels of nitrate in Iowa wells have been attributed to the use of commercial fertilizers and the disposal of manure (Kross et. al., 1997). This study reports that 35 percent of wells less than 15 meters (50 feet) deep have average nitrate levels over 10 mg/L. Similar work in Ontario reports 8 percent of domestic wells in exceedance of the Canadian Guideline for Drinking Water for nitrate (10 mg/L N as NO_3) and a further 7 percent exceeding guidelines for coliform bacteria (Waterloo Centre for Groundwater Research, 1993). In a recent study of 500 wells in Saskatchewan, the authors report that 35 percent of wells sampled exceeded one or more health-related objective. Health risks were defined by nitrate, coliform bacteria, arsenic, and selenium concentrations. The sources of pollution were attributed to both point and non-point source contamination (Sketchell and Shaheen, 2000).

Although there is a solid link between activities on the landscape and groundwater pollution, the relative importance of point versus non-point source pollution of groundwater wells is not always clear. The significance of each most likely varies under different conditions. Farm practices, management of domestic waste, soil and landscape characteristics and climate may all play a significant role in the transport of contaminants. In the high rainfall region of the Fraser Valley in British Columbia, researchers identified elevated nitrate concentrations over wide areas of an important shallow aquifer. Nitrate concentrations appeared to be consistent with agricultural land use patterns. Nitrogen balance calculations over time indicated that agricultural production was contributing to widespread nitrogen enrichment of groundwater (Zebarth et al., 1998). Similar work conducted in New Zealand indicated that nitrate concentrations in groundwater increased as the proportion of land in dairy production increased but the authors concluded that localized, site-specific factors may have as great an impact as general land use (McLay et al., 2001). In areas of low annual precipitation and high capacity for NO_3 storage by glacial till, recharge of groundwater is slower and contaminant transport may have delayed impacts on aquifer water quality (Kinchen et al., 1997).

Many well water studies are based on a small sampling of selected monitoring wells within large study areas. Seldom are studies designed to sample all the wells within a prescribed area. This analysis takes advantage of water quality data from a complete population of wells in a single Rural Municipality in Saskatchewan. It is an interpretative exercise combining the findings of the previous groundwater survey with existing natural resource data. The work focuses only on nitrogen and phosphorus concentrations in the water well samples. Interpretations were made in a GIS environment and exact global positioning of each well permitted the overlay of various, geo-referenced biophysical and land management datasets to investigate potential connections between observed water quality and farm management practices. The principle data layers used were 1:100,000 soil survey data, 1:50,000 topographic data with hydrographic data, and a point position map of existing intensive livestock operations.

Objectives

The objectives of this study are to determine the extent of nitrogen and phosphorus contamination in the groundwater of the Rural Municipality of Leroy, and to deduce the sources of contamination and the most likely modes of contaminant transport using only existing data. The analysis was conducted without the benefit of further data collection. Data types include information about well properties, land use, farm management practices and selected water quality parameters, obtained from the original Leroy well water study ('Groundwater Characterization in RM of Leroy', March 2001.) Soils databases, Canadian census information, topographic data and hydrographic data were also drawn upon to analyze water quality data in a GIS environment.

Background: Original RM of Leroy Water Well Study

A comprehensive study was initiated in 1999 to characterize the groundwater in the Rural Municipality of Leroy (RM 339) in central Saskatchewan. The project was undertaken jointly by AAFC-PFRA (Watrous office) and WateResearch Corp. Funding was provided by the Canada-Saskatchewan Agri-Food Innovation Fund (AFIF) and the Canadian Adaptation and Rural Development in Saskatchewan program (CARDS).

The objectives of the project were to describe all the wells in the rural municipality in terms of:

- Physical characteristics including depth, construction type and site factors,
- Water quality in terms of chemical parameters,
- Water management practices such as the use of water treatment devices, and

- Water well owners' attitudes toward selected issues such as water safety.

The Leroy study attempted to locate the entire population of existing, active wells in the rural municipality, using GPS technology. Every well was sampled by drawing raw water samples from outside taps, bypassing any treatment systems. Well storage volumes were calculated and sufficient water was pumped from each well to ensure that samples were representative of the aquifer. A number of tests including pH, turbidity, conductivity, temperature, and dissolved oxygen, were performed in the field by the sampling staff and some site characteristics were recorded by staff while at each well. Bacterial sampling was not included in the original study. Water samples were analyzed for a suite of chemical parameters by Saskatchewan Research Council and WateResearch Corp. Additional farm practice and water management information was obtained from well owners using questionnaires. For a more detailed description of the sampling methodology used in the study refer to 'Groundwater Characterization in RM of Leroy', March 2001.

A provincial water well database lists 208 wells in RM 339. More than 70 percent of these are small diameter (< 12 inches). Of the total 208 wells, 109 active and 34 abandoned wells were identified by the Leroy Water Well project. Of the known abandoned wells, only 4 were known to be sealed. More than 30 percent of the wells cannot be located and proper decommissioning cannot be recalled by the present landowners.

Description of the Study Area

Most of the RM lies within the Quill Lake Plain, a gently undulating to rolling till plain with some glacio-fluvial deposits on the surface. The area is in the Black soil zone and most of the soils are medium to medium-fine textured but there are many pockets of sand and gravel. The region receives approximately 300 mm of precipitation annually. Generally, the area slopes from northwest to southeast from an elevation of 592 meters above sea level (masl) to 525 masl. Lanigan Creek drains the upland area and flows south, exiting the RM at the southwest corner.

Two major deep aquifers underlie the study area; the Hatfield Valley Aquifer and the Wynyard Aquifer. The two formations are connected hydraulically and the water quality of both aquifers is quite poor due to high levels of dissolved solids. Wells completed in these formations provide water that is generally unsuitable for human drinking water but acceptable for livestock watering. Most of the wells that are used for domestic purposes are shallow wells, and many of these are completed in shallow, surficial deposits of sand and gravel. Half of the drilled wells in the RM were developed after 1990 whereas 79 percent of the dug or bored wells were developed prior to 1990.

The land use in the RM of Leroy is predominantly agricultural. There is a total of 195 farms consisting approximately 185,000 acres of cropped land, including approximately 6,000 acres of summerfallow, and 5,000 acres of tame and native pasture. The area supports approximately 3,000 head of cattle and 50,000 pigs. Much of the swine population is contained within a few intensive operations. Three quarters of the cropped land receives commercial fertilizer applications and manure is applied to about 350 acres of cropland.

Method

The completeness of the database offers a unique opportunity to attempt to make linkages between well water quality, soil and landscape factors, and land management practices. Although the data present only a one-time snapshot of the water quality in the RM, the original study captured the entire population of active wells and the sampling was conducted over a short period of time; September and October of 1999. The narrow sampling time-frame should have partially controlled for temporal factors that cause variability in the characteristics of the groundwater. The Leroy Water Well project reported nitrogen in water in the forms of ammonia-N and nitrate-N. Ammonia was determined by the phenate colourimetric method. Nitrate-N and nitrite-N were determined together using the hydrazine reduction colourimetric method and reported together as NO_3-N. Total nitrogen was reported as the sum of ammonia and nitrate/nitrite. Values reported and used in this analysis are milligrams per liter of N. Similarly, phosphorus values are reported in milligrams per liter of Total P. This analysis was conducted by overlaying the N and P values from the individual wells onto various other data layers. Statistical significance of relationships that appeared through the mapping overlays were tested using one-way ANOVA procedures, t-tests, and non-parametric tests. Significance is reported at the level of $\alpha = 0.05$.

The original study included a questionnaire that was completed by each well owner. The questionnaire collected information about well construction, water use, water treatment and the types of activities taking place in proximity to the wells. This study makes use of some of the questionnaire responses concerning farm practice. Well owners were asked to indicate the distance from the well to septic fields, fuel storage tanks, corrals, feedlots, manure storage areas, and lands to which pesticides, chemical fertilizers and manure had been applied. Response categories were less than 50 meters, 50 to 100 meters and more than 100 meters for septic fields and fuel storage sites. For all other activities, respondents indicated whether or not the activity took place within 50 meters of the well. These distances are used as grouping variables for analysis of variance of observed nitrate and phosphorus levels. A copy of the original questionnaire is available in ‘Groundwater Characterization in RM of Leroy’ (March 2001).

Results and Discussion

i) Characterization and Distribution of Wells

Figure 1 shows the distribution of all wells on a topographic representation of the entire RM. Individual wells have been plotted with symbols that distinguish large from small diameter wells and the elevation of the well head is displayed beside the symbol. Large diameter wells are also shallow wells, in almost all cases. In this study, shallow has been, somewhat arbitrarily, defined as less than 100 feet deep. Figure 2 shows the coincidence of well depth and casing diameter. Individual wells are identified with symbols identifying both parameters. Table 1 indicates the statistical significance of this relationship. The frequency table shows that 88 percent of the large diameter wells are less than 100 feet deep and alternatively that 70 percent of the deep wells are small diameter. The Chi-Square is highly significant ($p<0.0001$). Because of this correlation, well depth has been chosen as a measure that will be used primarily throughout this study rather than using both depth and diameter. Figure 3 shows the well location with respect to the two major aquifers in the area. It is clear that most of the small diameter wells are in the southern part of the RM and completed into the deeper formations; the Hatfield Valley and Wynyard aquifers.

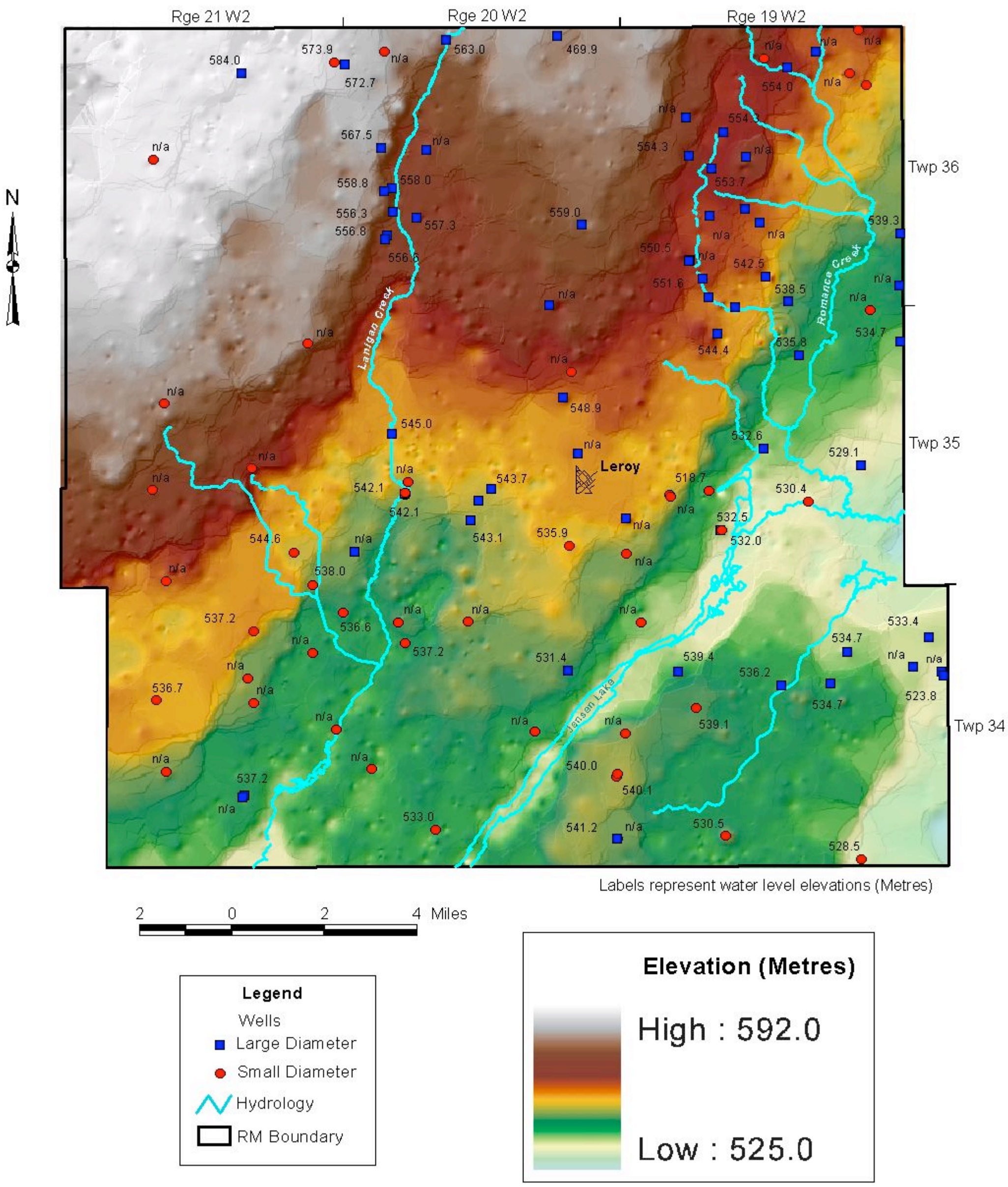
Table 1. Well Depth by Well Diameter

	Large (>12 in.)	Small (<12 in.)
Shallow (<100 ft.)	52 (88.1%)	14 (29.8%)
Deep (>100 ft.)	7 (11.9%)	33 (70.2%)
Total	59	47

x^2 $p<0.0001$

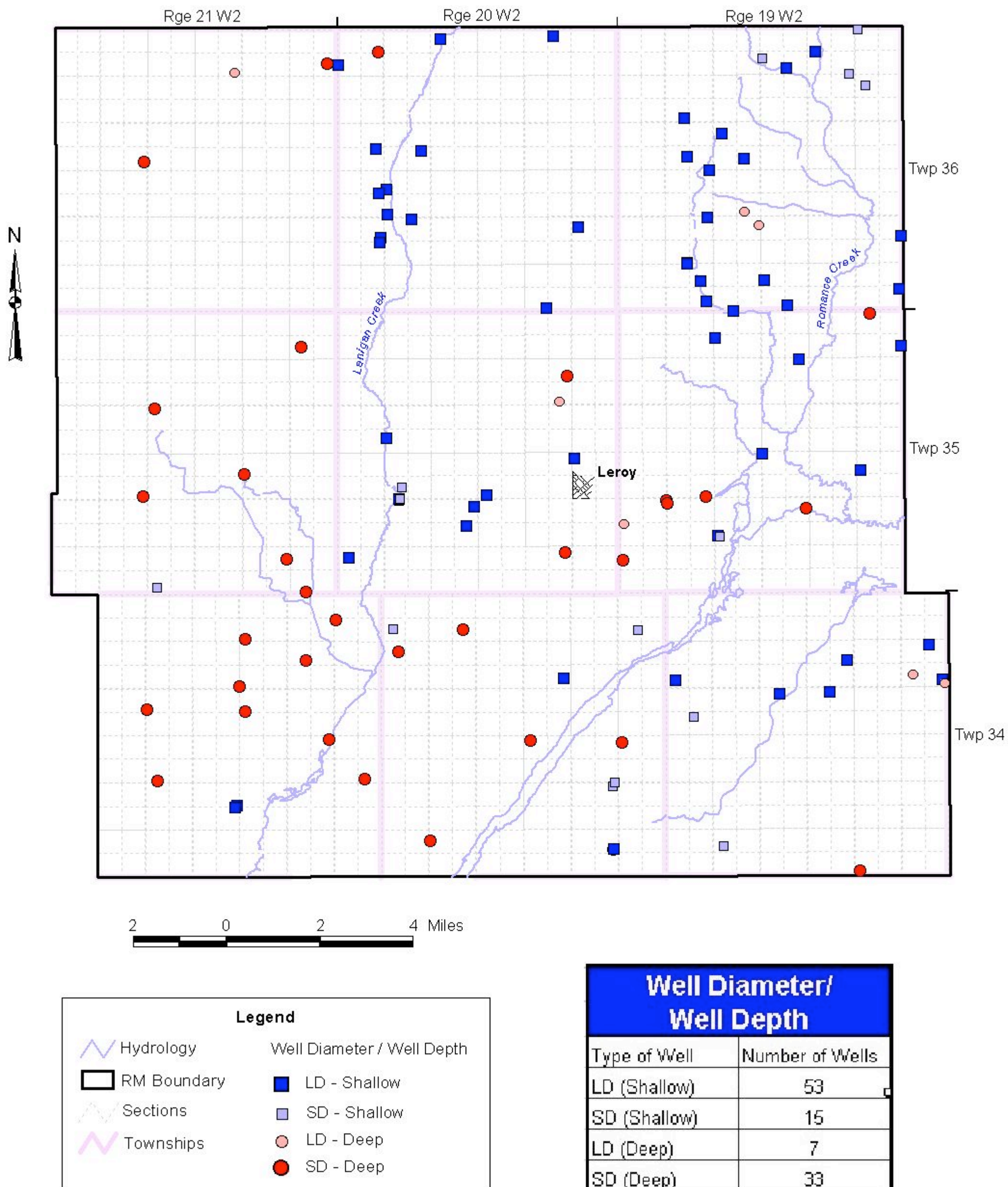
Shallow wells are mainly in the northern area and in obvious proximity to surface waterways. This proximity is evident in Figure 4. Five hundred and 1000 meter buffers have been placed around the major watercourses. Eighty percent of the wells located within the 500 m buffer are shallow. Of the total number of shallow wells, 62 percent of them are located within 1000 meters of a major watercourse. It is likely that many of these shallow wells are completed in coarse-textured fluvial deposits associated with water bodies and that contaminants may be introduced to shallow groundwater from surface water bodies or conversely, that surface water may be contaminated through discharge of polluted groundwater.

Figure 1. Digital Elevation Model and Water Levels (Metres)



Sources:
Hydrology & DEM - 1:50,000 NTS, 1997, ISC.
Wells & DEM - GPS Trimble 4700, PFRA.

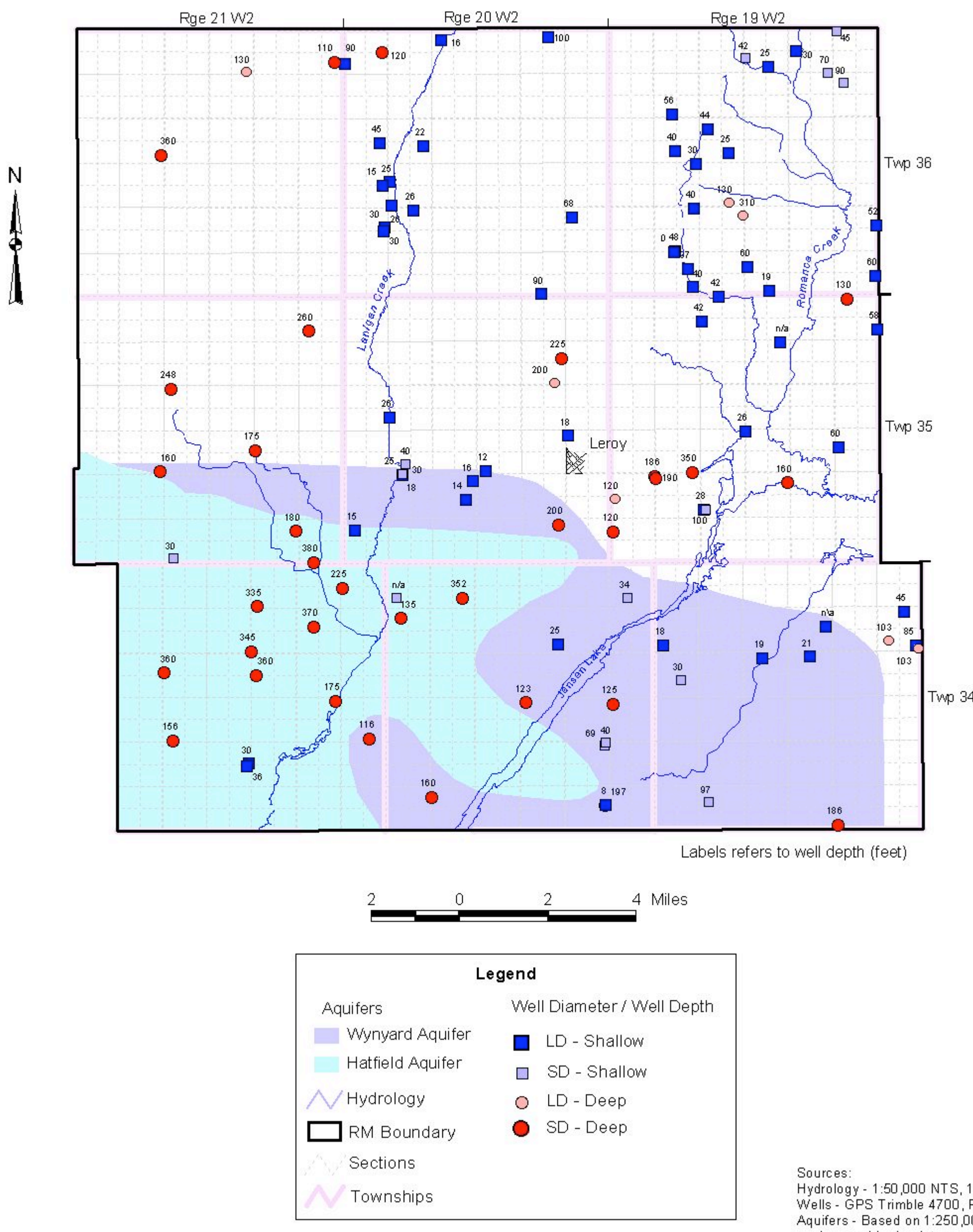
Figure 2. Well Diameter and Well Depth



Well Diameter/ Well Depth	
Type of Well	Number of Wells
LD (Shallow)	53
SD (Shallow)	15
LD (Deep)	7
SD (Deep)	33
TOTAL	**108**

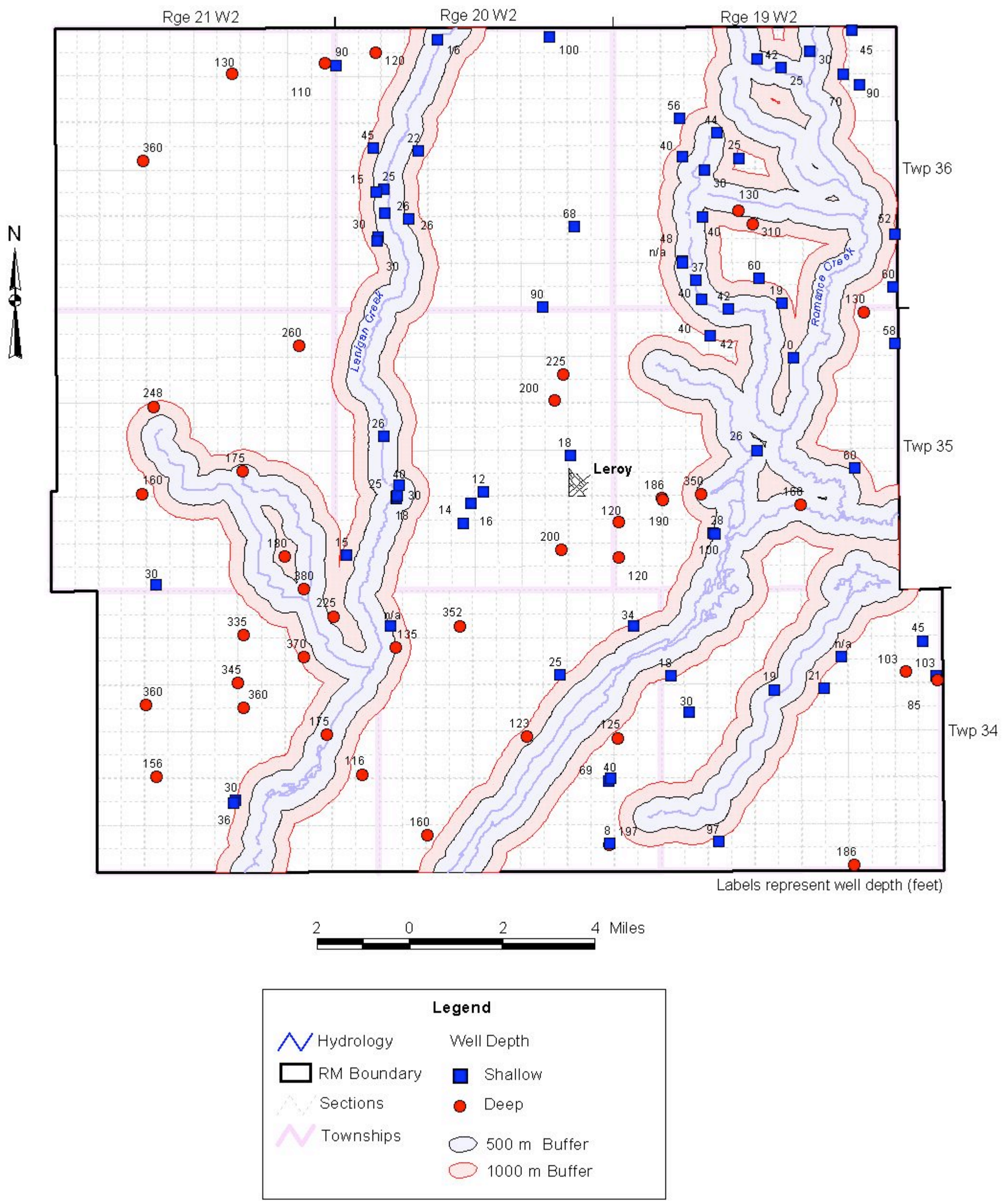
Sources:
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

Figure 3. Well Type and Possible Water Sources (Aquifers and Hydrology)



Sources:
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.
Aquifers - Based on 1:250,000 bedrock geology and bedrock topography surface map, SRC.

Figure 4. Wells Within Stream Buffers



Sources:
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

ii) Nitrogen

Graph 1 shows the distribution and summary statistics for observed nitrate/nitrite concentrations. Observed levels ranged from 0.01 to 213.50 mg/L with a mean of 15.60 mg/L. This mean is higher than the Canadian human health guideline of 10 mg/L. The graph shows that greater than 65% of the samples were under 2.5 mg/L N as nitrate/nitrite. The variation is wide among the remaining third with several extremely high values. Despite the presence of outliers, twenty-six of the 108 wells, or 25 percent, actually exceed the health guideline. Of these, all but one, are from wells less than 100 feet deep. Most of the analysis makes use of four groupings of nitrate data: less than 5 mg/L, 5 to 10 mg/L, 10 to 100 mg/L and over 100 mg/L. These categories are arbitrary but were created with reference to the human health guideline of 10 mg/L. The first two classes are below the guideline, the other two above. There is a sufficient number of cases in each class to permit analysis.

Figure 5 shows the levels of nitrate contamination as well as symbols that indicate whether the well is shallow or deep. Nitrate contamination is clearly associated with shallow wells. One-way analysis of variance of nitrate concentration by depth yields a highly significant relationship ($p = 0.0035$). The mean nitrate concentration in shallow wells is 23.44 mg/L whereas the mean in deep wells is 2.59 mg/L. It is also apparent in Figure 5 that the high nitrate levels are clustered in three distinct areas of the RM; the northeast corner, the north central area along Lanigan Creek, and in the southeast of the RM.

An attempt was made to use vegetative land cover to explain variation in well water quality but it was not successful. Ninety percent of the land area is devoted to cropped agriculture. Four percent is in tame or native pasture. Of the remaining few percent, much is represented by the riparian areas surrounding water courses. With such a degree of homogeneity of land use, it was not possible to identify vegetative factors that may be influencing groundwater.

An overlay was done to assess the role that soil texture may play in either facilitating or preventing the transport of contaminants to groundwater. Figure 6 shows dominant soil texture classes in the RM. The areas of highest nitrate levels tend to occur on the coarse-textured soil types. Although medium textures dominate the RM, the two wells located on coarse-textured soils have nitrate concentrations above 10 mg/L. Four of twelve wells located in moderately coarse textured soils were above the nitrate guideline level. The area in the southeast portion of the RM is dominantly fine sandy loam with small areas of coarser textured materials. Groundwater in these areas may be more susceptible to contamination from fertilizer and manure applied to surface soils. Only 20 percent of the wells in medium textured or loam materials were high in nitrates. These soils would be considered relatively impervious to leaching nitrates although they may be prone to the transport of nitrates and organic matter through water erosion and well contamination through the connections between surface water and shallow aquifers. Unexpectedly, half of the finest textured soils in the RM (loam to clay loam) showed elevated nitrate levels. This might be explained by presence of sand and gravel deposits. The soil survey data include a field that records the mappers' estimation of the extent of sand and gravel deposits within a soil polygon. This information is based almost entirely on visual indicators of economic excavations for sands and gravels. Within those boundaries, an estimate had been made of the area of the polygon that is occupied by sandy and gravelly materials. Figure 7 shows the extent of sands and gravels in the RM. Most of the wells with high nitrate levels are in close proximity to areas that contain sand and gravel deposits. In particular, the area in the northeast of the RM, which has a number of contaminated wells, shows a significant area where sandy and gravelly materials occupy up to 15 percent of the area as well as an area where gravelly materials occupy from 15 to 40 percent of the area. It should be noted that the boundaries of these areas were not delineated on the basis of the sand and gravel but rather on other soil characteristics. Nevertheless, the presence of gravelly materials, in sufficient quantity to justify excavation, may have implications for both the movement of surface contamination to groundwater and also the cross-contamination of a number of wells by transport of contaminants from a single well to many others through sand and gravel seams. The potential for connections between wells is most apparent in the northeast portion of the RM.

Graph 1. Nitrate / Nitrite Levels in Wells (mg/L)

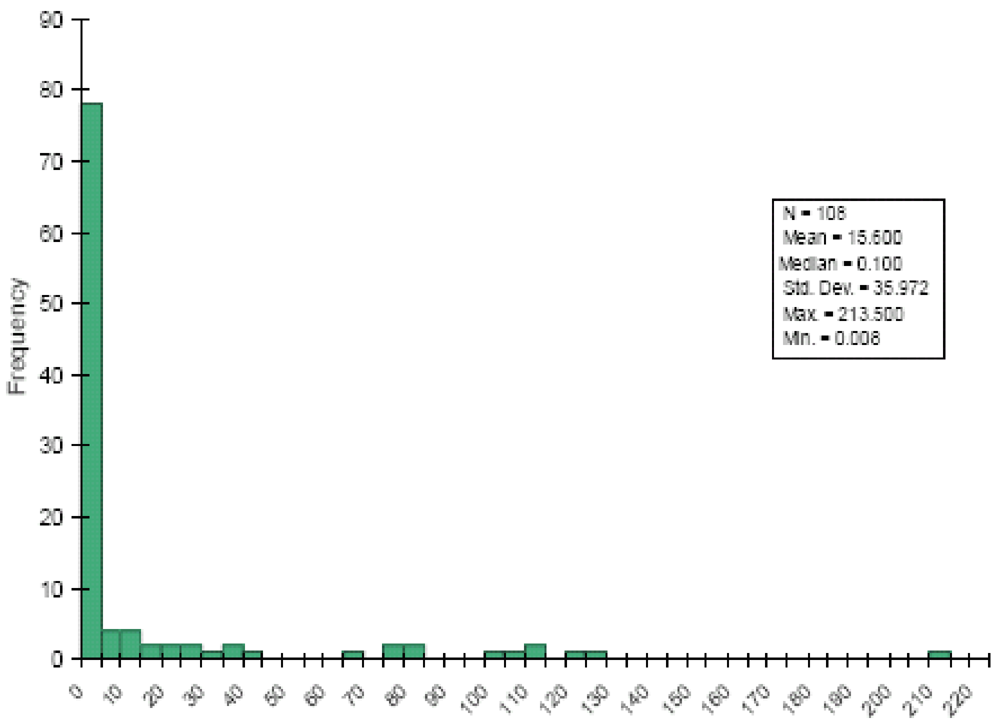
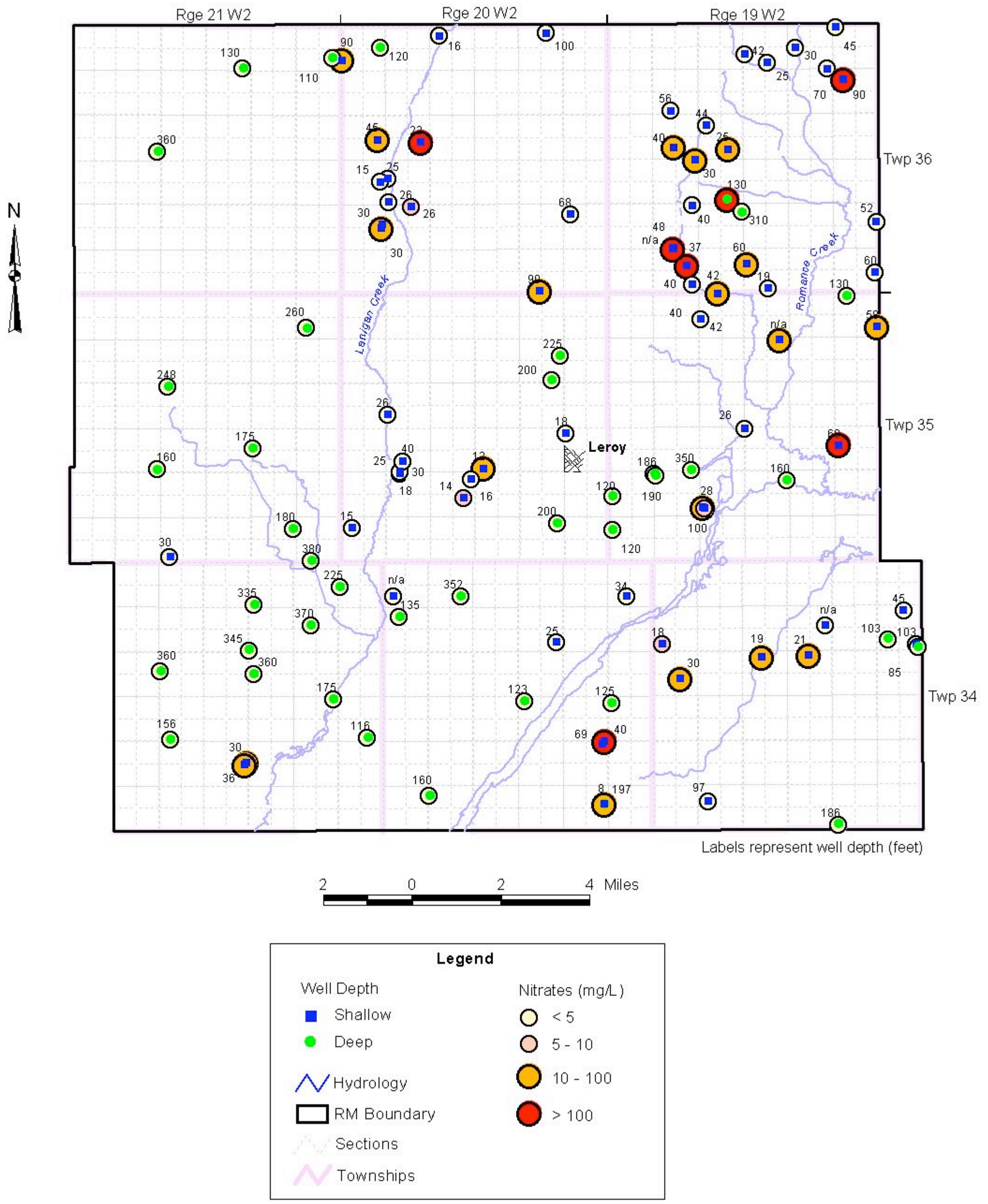
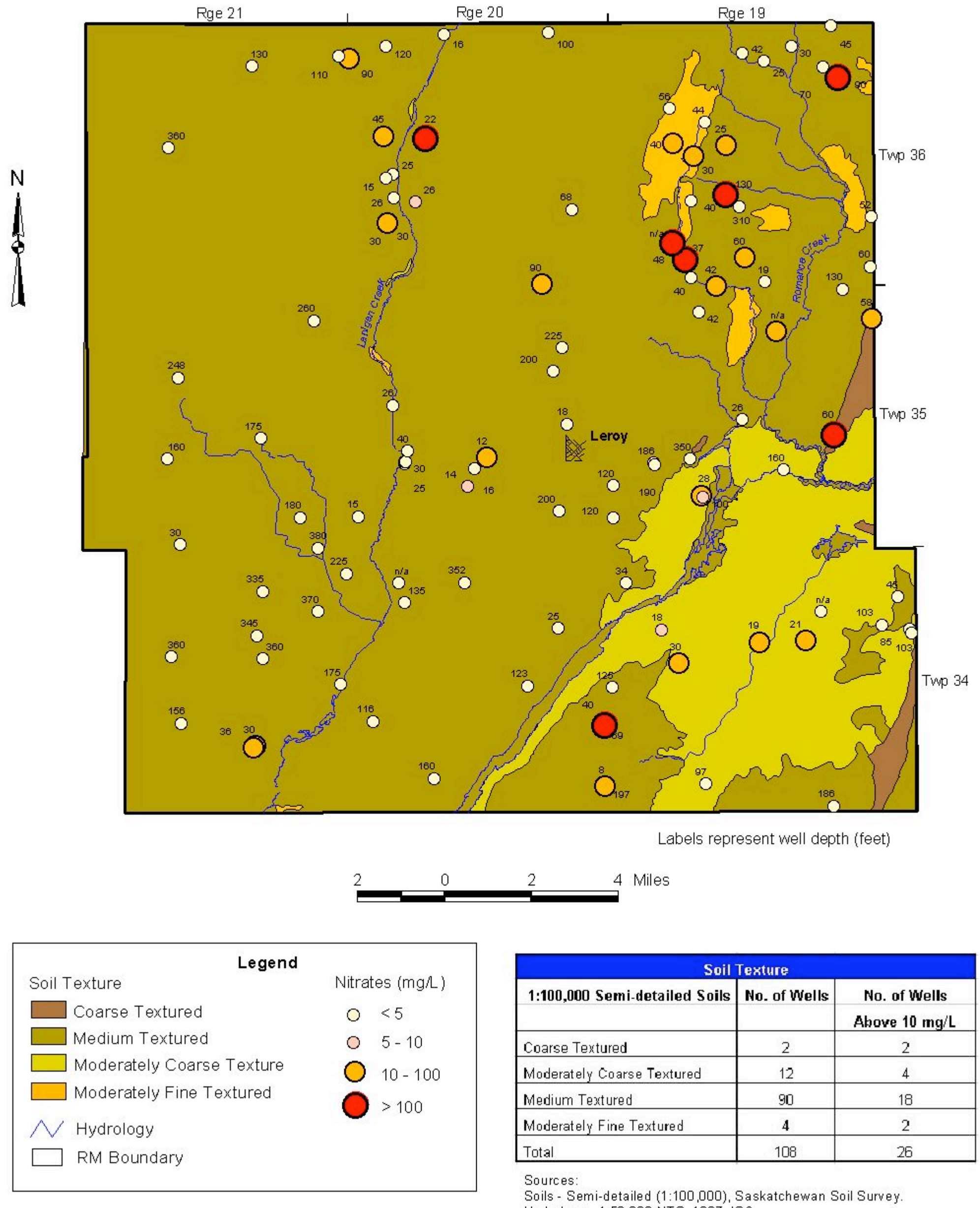


Figure 5. Nitrates and Well Depth



Sources:
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

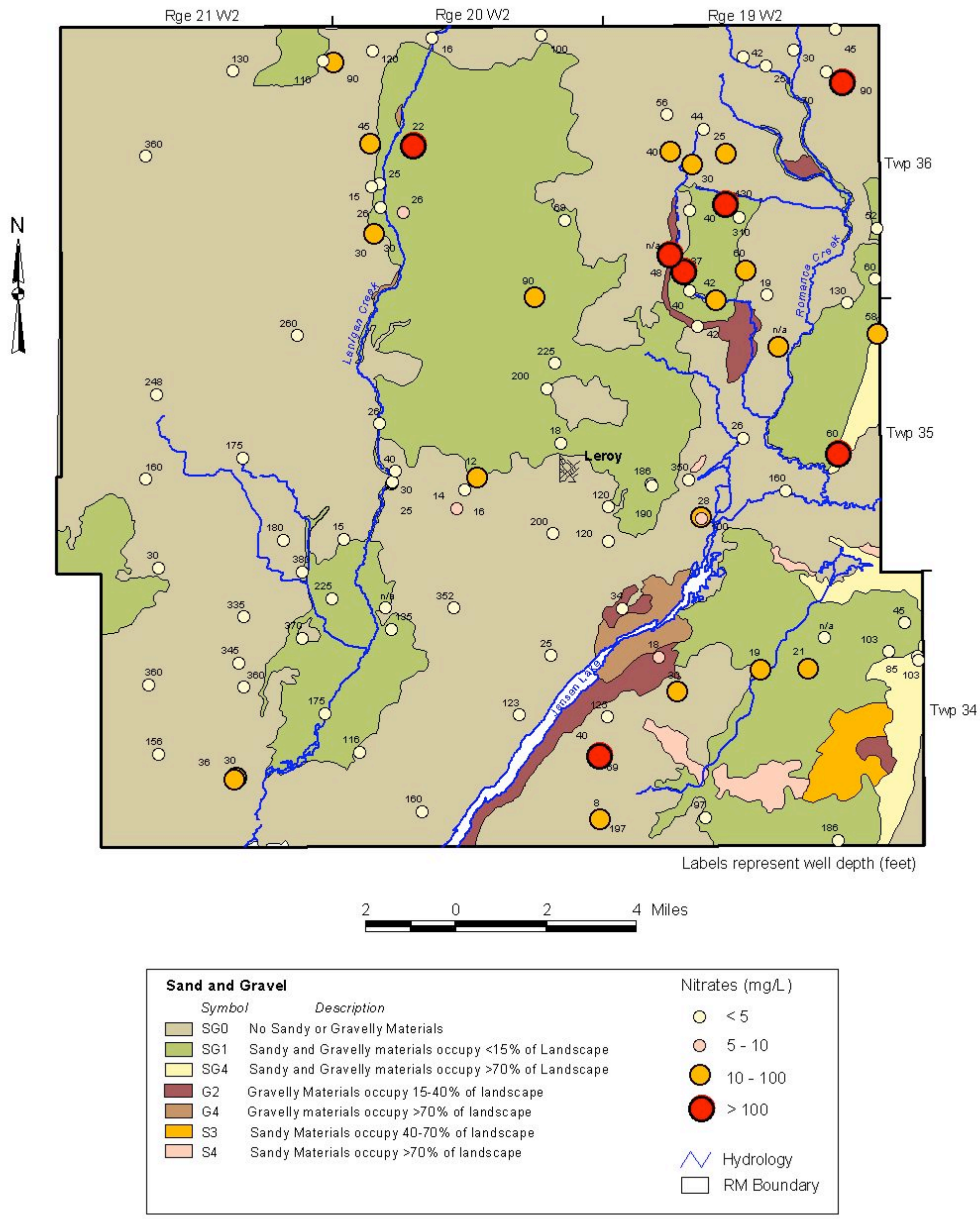
Figure 6. Soil Texture and Nitrates



Soil Texture		
1:100,000 Semi-detailed Soils	No. of Wells	No. of Wells Above 10 mg/L
Coarse Textured	2	2
Moderately Coarse Textured	12	4
Medium Textured	90	18
Moderately Fine Textured	4	2
Total	108	26

Sources:
Soils - Semi-detailed (1:100,000), Saskatchewan Soil Survey.
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

Figure 7. Sand and Gravel and Nitrates

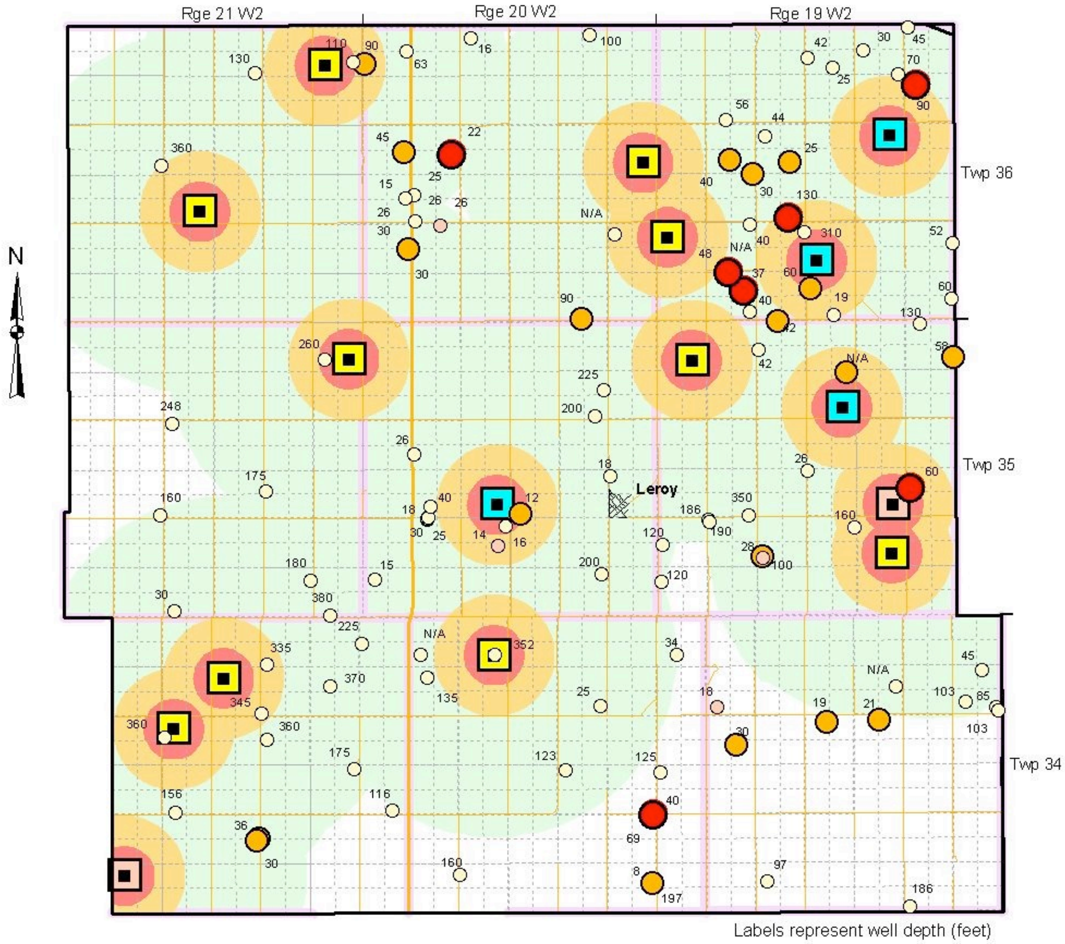


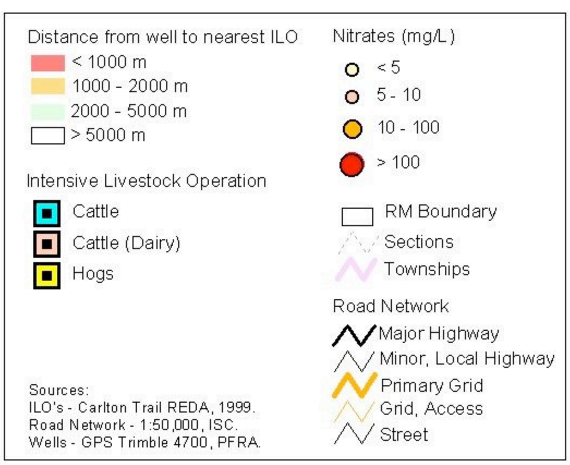
Sources:
Soils - Semi-detailed (1:100,000), Saskatchewan Soil Survey.
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

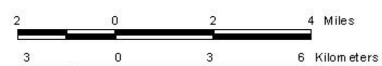
iii) Proximity to Intensive Livestock Operations

Due to the high density of livestock in the RM, a data layer was created on the distance from each well to the nearest intensive livestock operation. Operations were located by the centre of the quarter section in which the barn is situated. Figure 8 shows the location and type of the intensive livestock operations (ILOs) in the RM. The majority of the large operations are hog farms although there are two dairy operations and several feedlots for cattle. The ILOs are fairly evenly distributed in the RM and there does not appear to be an obvious connection between the locations of these farm units and the high nitrate wells. A simple regression of nitrate concentration with distance from nearest ILO did not yield any significant relationship (p= 0.373). However, when the distance data are categorized into groups, there is evidence of a positive relationship between nitrate levels and proximity to existing ILOs. An analysis of variance was conducted using nitrate concentrations and two distance groups: less than 2 km and more than 2 km. The mean of the group within 2 km was 25.7 mg/L compared to a mean of 13.2 mg/L for the group further from the nearest ILO. Although suggestive, this difference is not significant at the pre-determined 0.05 level (p=0.15) and there are a number of reasons to be cautious of this result. First, the distance calculation was not made on the livestock facility but rather the centre of the quarter section containing the facility. If a barn were located in the corner of a quarter-section, the calculation error would be more than 1000 meters. The potential impacts of manure on groundwater may result from the transport of nitrogen from field applied manure rather than runoff and leaching from confinement areas and barns. Unfortunately, this study did not have access to field records of manure application.

Figure 8. Proximity of Wells to ILO's







ILO Distance (m)		Nitrates
Well to Nearest ILO	No. of Wells	No. of Wells over 10 mg/L
0 - 1000 m	8	3
1,000 - 2,000 m	12	4
2,000 - 5,000 m	58	13
5,000 - 12,000 m	30	6
Total	**108**	**26**

iv) Yard Site Factors

As part of the Leroy study, well owners were asked to respond to a series of questions about the proximity of the well to a number of farm and household activities. These activities included corrals, feedlots, manure storage, septic fields, fuel storage areas, and lands that had received manure, fertilizer or pesticides. Figure 9 shows the locations of the wells, the nitrate concentrations and a symbol which indicates if the well is within 50 meters of a livestock corral. There is a significant, positive relationship between nitrate concentration and the proximity of corrals (p=0.037). The mean nitrate concentration of wells within 50 meters of a corral was 34.2 mg/L in contrast with a mean of 12.8 mg/L for more distant wells. No significant relationships were identified with other individual site characteristics. Distance from sewage septic system, existence of a well cap or a well pit, and proximity to feedlots, manure storage areas and land which had had received manure applications were all factors that were tested and alone showed no statistical relationship with nitrate concentrations. Despite this lack of strong association with any of these factors individually, there is some evidence that they might be important contributors to nitrate pollution in some circumstances. Analysis of these variables may have been confounded by a lack of precise definition in the initial study. Corrals, feedlots and manure storage areas may not be clearly distinguished by well owners. An alternative way to analyze the data may have been to group all these activities as "areas of manure accumulation" and use the aggregated variable in the analysis.

If the 26 wells that exceed the nitrate guideline of 10 mg/L are examined separately, fully two-thirds of them have at least one of the identified risk factors associated with them. In other words, two out of three of the nitrate contaminated wells is associated with either a corral, is in close proximity to land receiving fertilizer applications, or is within 100 meters of a septic field.

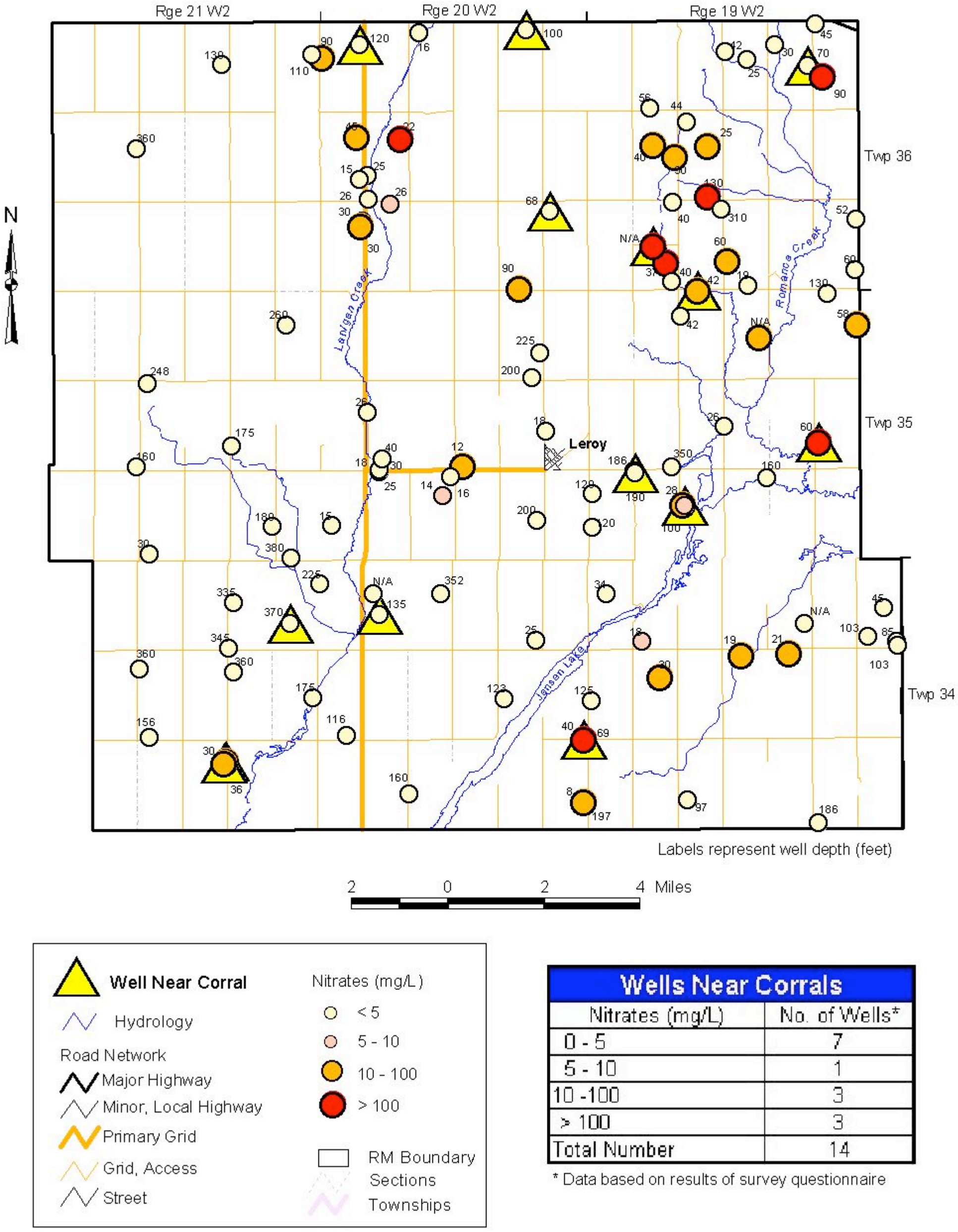
Another variable that showed evidence of effect on nitrate concentrations was the casing material used in the construction of the well. Table 2 shows a cross-tabulation of casing material by exceedance of nitrate guideline. Fibreglass and timber casings are associated with higher nitrate concentrations. Concrete, PVC, and steel casings are most often associated with lower nitrate levels. These trends are statistically significant on the basis of a Chi-square test (p=0.0026). This result may not reveal much about the contribution of construction material to susceptibility to contamination. Steel and PVC casings in particular are used to complete deep wells. It has been already established that deep wells are much less likely to be contaminated with nitrate than shallow wells. Similarly, timber cribbing is most likely to be associated with older, shallow wells which may have higher levels of nitrate for reasons distinct from materials used in construction. There is a common assumption that wooden cribbing may deteriorate and actually be the source of nitrogen in some contaminated wells. Despite widespread acceptance of this notion, no documentation of this was found in the literature.

Table 2. Cross Tabulation of Exceedance of Nitrate Health Guideline (10 mg/L as NO_3) by Well Casing Construction Material

Frequency (Column %)	NO3 > 10 mg/L	NO3 < 10 mg/L	Total
Concrete	6 (24%)	15 (19.2%)	21
Copper	0 (0%)	2 (2.6%)	2
Fiberglass	4 (16%)	1 (1.3%)	5
Galvanized	4 (16%)	5 (6.4%)	9
Galvanized & Timber	1 (4%)	3 (3.9%)	4
Iron	0 (0%)	2 (2.6%)	2
PVC	1 (4%)	31 (39.7%)	32
PVC & Timber	0 (0%)	1 (1.3%)	1
Porous Concrete	1 (4%)	0 (0%)	1
Steel	1 (4%)	8 (10.3%)	9
Timber	4 (16%)	10 (12.8%)	16
Steel & Timber	1 (4%)	0 (0%)	1
Total	25	78	103

Chi-square $p = 0.0026$
Effective Sample Size = 103
Frequency missing = 5

Figure 9. Wells Near Corrals



Wells Near Corrals

Nitrates (mg/L)	No. of Wells*
0 - 5	7
5 - 10	1
10 -100	3
> 100	3
Total Number	14

* Data based on results of survey questionnaire

Sources:
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

v) Phosphorus

Graph 2 shows the distribution and summary statistics for total phosphorus. Levels in the wells ranged from 0 (below detection limit) to 0.66 mg/L. The range is very large (0.02 to 0.66 mg/L) with a mean of 0.06 mg/L and a median of 0.02. Similar to the distribution of nitrate, most values are very small but approximately 25% of the wells have much higher P concentrations than the average. There are very few existing guidelines for acceptable levels of phosphorus in water largely due to the fact that there is no identified human health risk associated with phosphorus. Australia uses an objective of 0.2 mg/L for the public water supply. The major environmental concerns about phosphorus are related to its plant nutrient value to algae in surface waters.

The analysis conducted using nitrate concentrations was repeated using the concentrations of total phosphorus reported by the original study. No significant relationships were discovered. An insignificant trend was found between phosphorus and well depth. Phosphorus levels are negatively associated with depth. Wells over 100 feet deep tended to have higher levels of phosphorus than shallow wells (p= 0.103). There is no obvious explanation for this finding except that naturally occurring levels in deep groundwater are high relative to those in shallow aquifers and that land management practices contribute little to phosphorus loading of groundwater. There seems to be no relationship between phosphorus and nearby corrals, manure storage, household sewage, intensive livestock operations or land to which manure and chemical fertilizers had been applied. Nor was there a relationship with phosphorus and soil texture. Figure 10 shows the well locations with symbols denoting three arbitrary classes of phosphorus concentrations. No spatial pattern is evident, as it was for nitrate levels.

Graph 2. Total Phosphorus Levels in Wells (mg/L)

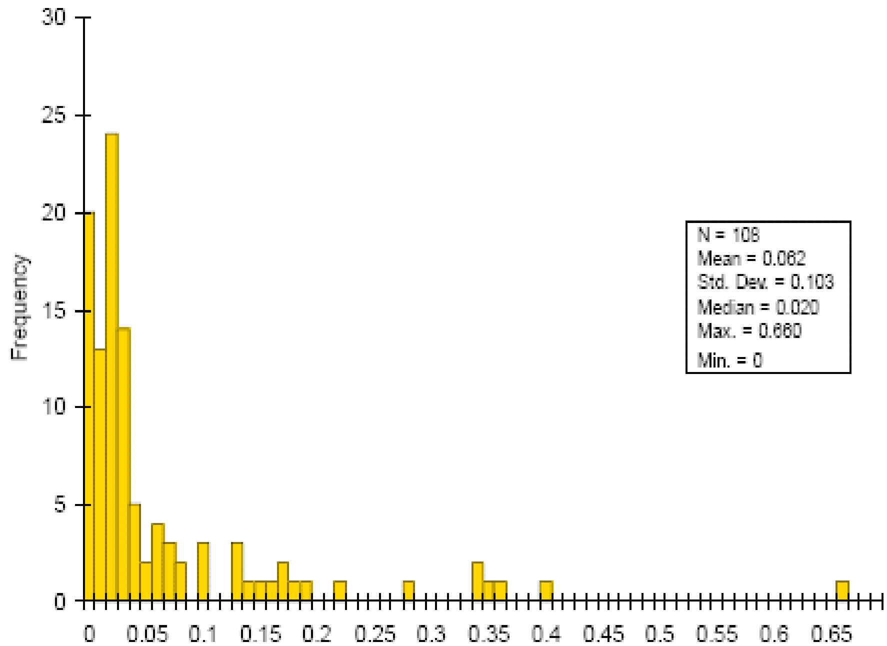
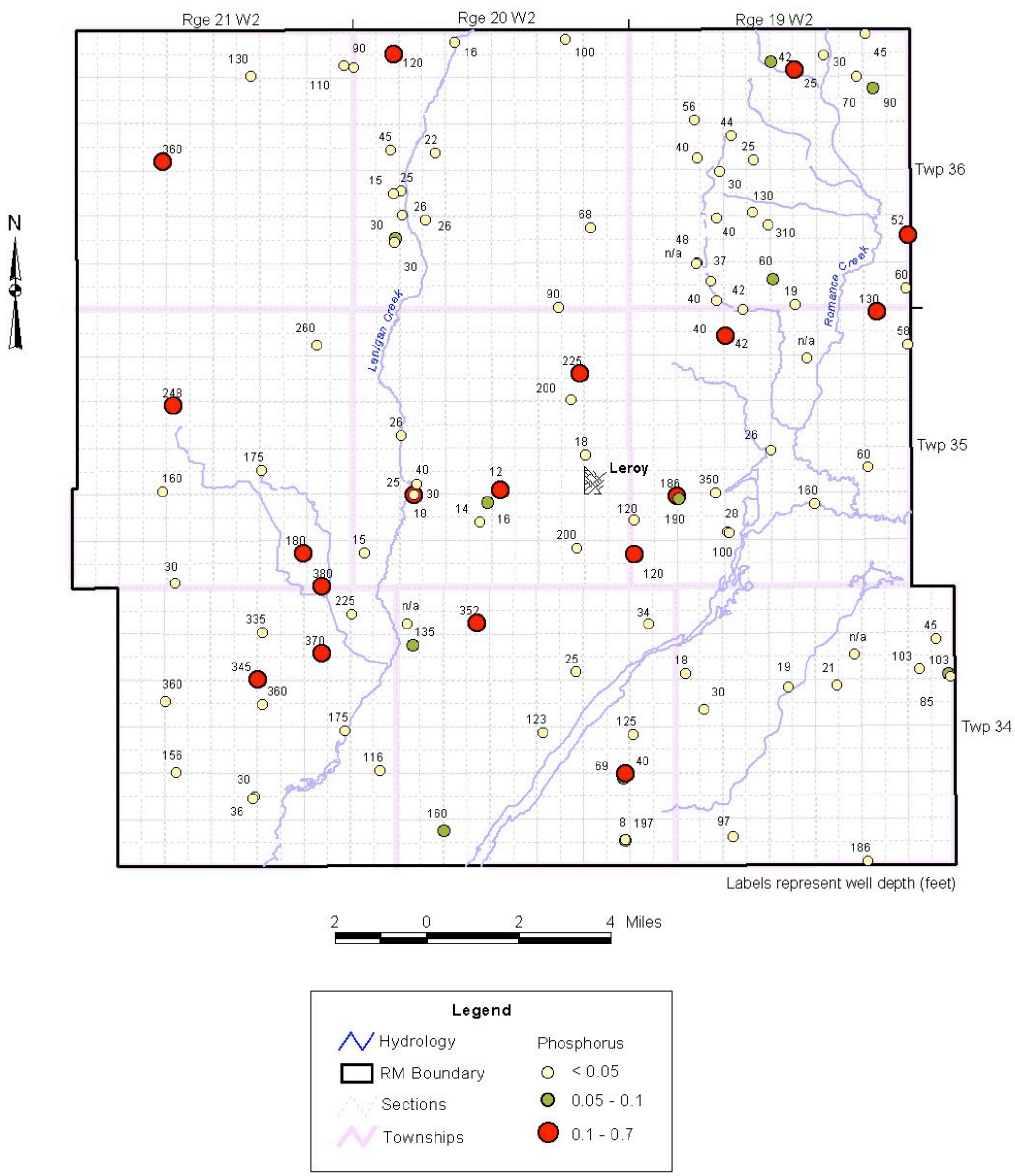


Figure 10. Phosphorus and Well Depth



Sources:
Hydrology - 1:50,000 NTS, 1997, ISC.
Wells - GPS Trimble 4700, PFRA.

Conclusions

Nitrate levels in the wells in the RM of Leroy are high. The mean nitrate concentration of (15.6 mg/L) is higher than the Health Canada guideline. This result is in part due to the effect of a few very high values. Six wells had nitrate levels above 100 mg/L and one well was above 200 mg/L. However, 25 percent of all the wells would be considered unfit for human consumption. These values indicate very high levels of nitrate contamination.

This analysis revealed a clustering of contaminated wells in three general areas of the RM. Nitrate contamination is largely associated with shallow, large diameter wells in the northern and southeastern parts of the municipality. Deep wells completed in the Hatfield Valley and Wynyard aquifers show much lower levels of nitrate. It seems probable that nitrogen is entering shallow groundwater from surface activities. Contamination routes are either through leaching or through surface runoff and by way of connections between surface flow and shallow aquifers. Both pathways are supported by the findings of this study. Nitrate contaminated wells are in close proximity to surface water bodies and also associated with coarse textured soils and soils that have identifiable deposits of sand and gravel. Sand and gravel may provide preferred pathways for flow of contaminants from the surface to shallow groundwater as well as function as conduits for high flow rates within an aquifer.

The nitrogen sources are almost certainly from point-source, agricultural activities and this study points to the likelihood that most nitrate contamination is resulting from activities that occur close to the wells. There is little evidence of widespread, non-point source contamination. No clear association with annual cropping in general is apparent. However, the predominance of farming as a land use in the municipality prevents any comparison with other land uses. Nitrogen enrichment of shallow groundwater may be occurring as a result of cropping practices but a set of control data would be required to perform the analysis.

Livestock operations are an identified source of nitrate. Contaminated wells are significantly associated with animal corrals. Other farm yard factors appear to contribute to nitrate pollution in some cases. These include septic fields and proximity to cropland that has received treatments of either manure or synthetic nitrogen fertilizers. Although not included in the original study, there is evidence that animal corrals which were used in the past may be the main source of nitrates in the wells. Informal conversations with a couple of well owners indicated proximity of contaminated wells to corrals which were used in the past but are no longer used and were not reported on the questionnaires. One of these sites was the well with over 200 mg/L nitrate. Given the low precipitation levels in central Saskatchewan, leaching of contaminants such as nitrate may take many years and even decades to occur.

A statistically insignificant ($p=0.15$) but suggestive finding was a relationship between nitrate levels and proximity to intensive livestock operations. The mean nitrate value was higher for wells within two kilometers of an existing ILO than for those at greater distance. Intensive animal facilities are a relatively new development in the mix of agricultural operations in the RM so it is difficult to draw a conclusion from this result. There may have been an impact of applied manure on shallow groundwater already or the finding may be coincidental. However, in view of the suggestion that leaching may take a great many years to occur, high levels of manure production and application to cropland may represent an impact to shallow groundwater that will not be realized for a long time.

There is an indication that nitrate contamination is associated with timber cribbing. However, this study is not able to isolate the possible role that deteriorating wood may play in raising nitrate levels. Timber cribbing is also associated with shallow wells and old wells which are in close proximity to many of the domestic and livestock-related activities on the farm. Both shallow depth and point-source pollution may be the actual causes of contamination but timber cribbing is commonly cited as a contaminant source. It would be interesting to conduct a properly controlled study to assess the potential problem.

Phosphorus levels in the wells varied widely but this analysis was unable to discover underlying factors that might explain this variability.

Recommendations

This analysis strongly suggests that nitrate contamination of shallow groundwater is caused by localized activities in the farmyard. A correlation was found between high nitrate levels and the proximity of wells to manure, household effluent and fertilizer use. Raising the level of awareness of well owners to the risks of exposing groundwater to nitrogen sources could perhaps prevent much of this contamination. Although, this study focuses on nitrogen, well water may also be contaminated by pesticides, solvents and other compounds by way of the same transport mechanisms that permit the movement of nitrate.

In order to protect shallow groundwater from contamination, various ‘beneficial management practices’ might be implemented. Careful siting of livestock containment areas, manure storage areas, and fertilizer and pesticide storage areas is critical. These risks should be located down-slope of contaminant sources wherever possible. Wellheads should be protected by raising the soil surface around the well to prevent runoff from accumulating at the wellhead. Livestock should not be permitted to get close to the well. Well pit construction should be avoided and pitless adaptors installed to minimize the risk of pollution at the well head. Wells should be routinely inspected for damage that may permit the inflow of water from anywhere but the developed aquifer. Finally, all wells that are abandoned or no longer in use should be properly decommissioned to prevent accidental contamination of shallow aquifers.

Further Study

This analysis makes use of existing data without new data being collected. However, there may be opportunities for valuable work to be done with respect to nitrate contamination of groundwater in the future by adding new data to the foundation that the original Leroy project provides. With the background data from the original study, a project that re-samples the wells or a subset of the wells may provide valuable insight into shallow aquifer contamination. New work might include sampling for other contaminants such as bacteria and pesticides. Mapping of shallow aquifers and groundwater flow may permit better identification of point source pollution. Measurement of contaminant leaching rates might provide insights into the time-frame over which migration of nitrates to shallow groundwater occurs. Data layers could also be developed to better describe practices regarding manure application to farmland. Questions were raised, during the course of the study, about the role of decaying wooden cribbing in nitrate contamination and the level of risk to groundwater that improperly abandoned wells might represent. The absence of information about these risks in the literature also suggests opportunity for further study.

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