Hydrol. Earth Syst. Sci. Discuss., 10, 1553–1579, 2013
www.hydrol-earth-syst-sci-discuss.net/10/1553/2013/
doi:10.5194/hessd-10-1553-2013

Hydrology and Earth System Sciences
Open Access
Discussions

Statistical analysis to characterize transport of nutrients in groundwater near an abandoned feedlot

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Received: 10 December 2012 – Accepted: 9 January 2013 – Published: 31 January 2013

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Surface water from a dugout pond and groundwater samples from seven shallow wells installed within an abandoned feedlot in northwestern Minnesota, USA. were analyzed for nutrients, ammonia, pH, temperature, and electrical conductivity (EC). In the study, multivariate statistical techniques including cluster and factor analyses were used to evaluate the interrelationship between the analyzed chemical species. The cluster and factor analyses grouped the analyzed chemical species into three different groupings or clusters based on the concentrations of the chemical species and physical parameters. From the factor analysis, approximately 78 % of the variability in the factor 1 was caused by electrical conductivity (EC), ammonium (NH_4^+), total carbon (TC), and total phosphorus (TP), while within factor 2; approximately 82 % of the variability was caused by temperature (T), pH, nitrate-nitrogen (NO_3-N), and ammonium (NH_4^+). The contribution of nitrate-N and ammonium could be attributed to the high rate of denitrification and/or the dissimilatory nitrate reduction to ammonium. The change in the concentration of nutrients is attributed to redox conditions, temperature variation, and the movement of nutrients from manure.

1 Introduction

Large feedlots have boosted the economies in many areas in the USA (Duncan et al., 1997) by creating jobs, food, and raising the economic potential of corn and other cereal markets, but mismanagement of these agricultural facilities has resulted in elevated concentration of nutrients in soil, water and air (Mielke and Ellis, 1979; Olson and Paterson, 2005). Most of the problems associated with feedlot pollution are from manure mismanagement, resulting in high concentrations of ammonia, odorous compounds, and nutrients (USEPA, 1999) in air, soil, surface water, and groundwater. Excessive nutrients, phosphorus and nitrate, in surface water and groundwater have been a major concern for the global world (Tappin, 2002).

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Large feedlots, when operated within a small and restricted area, have been termed concentrated animal feeding operations (CAFO); terminology coined in 1976 by the US Environmental Protection Agency (USEPA). There are different criteria for the definition of CAFO, but it depends mostly on the type and number of animals reared within the facility (USEPA, 2003). Confined or concentrated animals receive nutrient-rich feed, which enables faster growth and greater health, thereby creating elevated concentrations of nutrients in their excreta (Jongbloed and Lenis, 1998). CAFO or feedlot operations in the past did not encourage the use of a liner on the soil surfaces, but accumulated manure acted as impervious layer preventing the infiltration of urea and other waste from the livestock into the subsurface. During stormwater runoff when the feedlot is operational or abandoned, natural processes such as weathering and erosion set in resulting in the transportation of nutrients in soils, surface water (Burwell, 1974; Gilley and Risse, 2000) and groundwater. These nutrients can accumulate in nearby wetlands (Hopkinson, 1992; Ciria et al., 2005), be sequestered in soils (Craft, 2007), sorbed on biomass (Stewart et al., 1990; Ciria et al., 2005) and/or transported in streams. Excessive amount of the nutrients, especially phosphorus, creates conditions favorable for eutrophication which reduces the concentration of dissolved oxygen in surface water (Paine, 1976; Scott et al., 1998; Wyngaard et al., 2011).

Numerous scientists have used multivariate statistics to better understand groundwater pollution within different areas and also used it in reducing the complexity of large data sets (Vega et al., 1998; Zhang et al., 2009). Multivariate analysis is widely applied in elucidating environmental pollution problems (Carpenter et al., 1998; Anazawa et al., 2003; Boruvka et al., 2005; Yidana et al., 2008) and has been used to differentiate between anthropogenic and geogenic source of trace elements (Boruvka et al., 2005; Zhou et al., 2008; Krishna et al., 2010). Application of multivariate statistical analysis in groundwater and surface water geochemistry within and near feedlots can help determine the transport and fate of nutrients. Multivariate analysis is used in the simultaneous comparison of several parameters or chemical species. Most often, the multivariate statistics used for geochemical data analysis include cluster analysis, principal component analysis, factor analysis, and discriminant analysis. In this manuscript, multivariate statistical techniques, including cluster and factor analysis, are used to analysis groundwater data obtained from a feedlot abandoned in 2000.

At the feedlot, which operated from 1970 until 2000 and contained on average 1500 animal units, an ongoing study has focused on the nutrient budget and movement of phosphorus within the local groundwater system. The objectives of this study are to: (1) determine the relationship between nutrient concentration and groundwater movement, and (2) determine the major contributing nutrient to groundwater contamination within the study area. Due to lack of information or records on the feedlot, the mechanism of transport of nutrients has not been included in this manuscript but there is a comprehensive study at the site trying to understand the deposition, movement, and fate of nutrients at the site. The results would help feedlot operators to mitigate excessive nutrients in groundwater at active feedlots and guide remediation of abandoned sites.

2 Materials and methods

2.1 Study area

The study area is the former Crookston Cattle Company Feedlot (47°43.6′ N, 96°19.2′ W), which lies 25 km southeast of Crookston, Minnesota and about 64 km east of Grand Forks, North Dakota (Fig. 1). It is an abandoned feedlot situated on a sandy beach along the eastern margin of glacial Lake Agassiz. The feedlot, which contained as many as 1500 cattle during its operation from 1970–2000, is surrounded on the north and south by wetlands. The feedlot occupies an area of approximately 0.30 km^2 (30 ha) out of the 89 km^2 (8900 ha) acquired by the Minnesota Chapter of the Nature Conservancy (Gerla, 2000). The boundary of the study area is defined by the extent of the wells installed within the area.

The study area generally has a flat topography with about 2 m of relief and an elevation of approximately 332 m above m.s.l. Geologically, the area is characterized by Quaternary Red Lake Falls Formation (carbonate glacial till) that immediately underlies beach ridges that formed along the margins of glacial Lake Agassiz (Harris et al., 1974). The beach ridge is underlain by till at shallow depth and bounded by wetlands, thus constituting a comparatively simple hydrogeological system. The feedlot site was originally selected because of its coarse sandy soils that provide good drainage. The sandy unit has an approximate thickness ranging from 3.05 to 3.35 m along the beach ridge and 1.83 m within the wetlands. Currently, there is an ongoing study focusing on the nutrient budget and groundwater nutrient transport at the site.

2.2 Sampling collection and analysis

Shallow wells were installed and groundwater samples were collected and analyzed in the fall of 2010. During this period, six wells (DVPT, FLE, FLW, NWW, SPN, and SPS), two dugout pits (SGN and SGS), an excavated lagoon (POND) used in the past for manure disposal, and USGS Monitoring Well G08 with Minnesota unique well number 620668 (MDH, 2007) were used in the analysis and characterization of the groundwater flow. The elevation and location of the wells were taken using Etrex Vista Hcx Garmin Global Positioning Systems (GPS) and EAGL Electronic Laser Level (model 1000), respectively. The groundwater levels in the wells were measured using Solinst Model 101 Water Level Meter during the fall of 2010 for generating the equipotential lines in Fig. 2.

Groundwater samples were collected with different bailers after the wells have been thoroughly purged and allowed to recover. Two samples were collected at each site, filtered through a disposable 0.45 µm millipore filter membrane, and placed in a sterilized 250 milliliter (mL) high density polypropylene and 50 mL round amber glass sample bottles for chemical analyses. The samples were transported in an ice filled ice-chest prior to laboratory analysis. Temperature (T) and pH were measured using YSI pH100CC-04 pH meter while electrical conductivity (EC) was measured using HACH

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CO150 conductivity meter in situ. The electrodes of the equipments were calibrated before use. The chemical analyses of the groundwater samples were carried out in the Environmental Research and Analytical Laboratory of the University of North Dakota. The chemical species analyzed included the nutrients, ammonium (NH_4^+), and total organic carbon (TOC). The nutrients analyzed included total phosphate (TP), nitrate-nitrogen (NO_3-N), and nitrite-nitrogen (NO_2-N). NO_3-N and NO_2-N were measured using Ion Chromatography (Dionex DX-120) while TP and NH_4^+ were measured using HACH DR/2010 Spectrophotometer. TOC was measured using Shimadzu TOC Analyzer (model Vcsn). At selected times, stable oxygen and nitrogen isotopes in nitrates were measured at the University of Nebraska-Lincoln's Water Center. This analysis was done using the Micromass Optima Dual Inlet Isotope Ratio Mass Spectrometer. Laboratory quality assurance and quality control was done to ensure accurate measured concentration of the samples. This included addition of duplicate samples and reagent blanks in the analysis, and matrix spike analysis. The overall analytical recovery was between 80–120 % compared to the certified standard concentration.

2.3 Multivariate statistical techniques

The multivariate analyses done in this study includes cluster analysis (Q-mode) and factor analysis (R-mode). These statistical analyses were done using Systat 12 software (Systat Software, Inc. Chicago, IL, USA). The physical and chemical species analyzed using the multivariate statistical technique included T, EC, pH, TC, TP, NO_3-N, and NH_4^+. NO_2-N was not used in the multivariate analysis because more than one-half of the samples analyzed had concentrations below the detection limit of 0.1 mg L^{-1}.

2.3.1 Cluster analysis

Cluster analysis is an empirical analysis or a multivariate technique used to identify homogeneous groups of objects (Davis, 2002) or it shows similarities (or dissimilarities) between objects in a graphical form, with each cluster showing homogeneity within a

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multiple variable. Cluster analysis is done to minimize within-group variation and maximize between-group variation (Fernandez, 2002). In this study, the Q-mode hierarchical clustering with single linkage using Euclidean distance as the similarity measure was used to generate a dendrogram.

2.3.2 Factor analysis

Factor analysis examines the pattern of correlations (or covariances) between observed measures (DeCoster, 1998). This type of analysis reduces a set of intercorrelated data into compact or smaller latent variables called factors. Factor analysis is used in determining the most contributing variables within a particular data analysis. The variables used in the analysis produce various variances called eigenvalues. Most often factor analysis and principal component analysis are thought to be identical but the major difference between the principal component analysis and the factor analysis has to do with the random error in the variance observed in the data. Also, with the principal component analysis all the variables are used but with the factor analysis, the number of factors to be extracted is defined and scaled to the variance. In this study, the R-mode factor analysis was used using two factors to determine the interrelationship in a matrix of correlation between the variables being studied.

3 Results and discussion

3.1 Groundwater movement

The groundwater elevations measured within the wells ranged from 330.75 to 331.70 m (Table 1). These values were calculated from the measured water levels and the surveyed topography of the area. The groundwater elevation from each of the wells were contoured using the minimum curvature gridding algorithm in Golden Software Surfer 10 (Golden Software, Inc. Golden, CO, USA), which provided a good fit to the water table surface when compared to other gridding algorithms. Surfer produced the contours based on the initial hydraulic head values measured from each well. The water table contour produced was saved as a shape file, and imported into ArcGIS 10 software (Environmental Systems Research Institute (ESRI), Inc. Redlands, CA, USA). The shape file was georeferenced onto an aerial photo, which aided in determining the shallow groundwater flow direction.

Based on the conceptual model produced, groundwater appears to be preferentially recharged near the center of the feedlot (beach ridge) and flows a few meters before being discharged into the nearby wetlands in the NW and SE (Figs. 1 and 2). The highest water level of 331.70 m was measured in Well SPS while the lowest water level of 330.75 m was measured in Well NWW. Gauging sites with dugout pits (SGN and SGS) had measured water elevation of 330.40 m. This represented surface water elevation within the wetlands that are characterized by relatively flat topography.

The pond had a constant head value of 331.12 m. The untarred road in the northeastern part of the area where Well G08 is located has a no flow boundary where groundwater cannot move to the other end of the area. The beach ridge which act as a topographic and groundwater divide with a no flow boundary where water cannot to either sides of the divide. The equipotential lines are relatively parallel to the orientation of the beach ridge and the flow lines are perpendicular to the equipotential lines.

Water table elevations across the feedlot (Fig. 2) show that the longitudinal axis of the ridge corresponds closely to a local groundwater mound or divide, suggesting that the ridge creates a zone of local recharge. Wells SPN and DVPT are located near the divide. A slug test was performed on Well DVPT using Hvorslev method and a hydraulic conductivity of 24 m day^{-1} was calculated. This unit corresponds to well sorted sand or sand and gravel units that allows more infiltration of precipitation. Groundwater flow occurs away from the main axis of the ridge, and is at least partially discharged along the margins of the ridge, where the POND, Well NWW and dugout pits SGN and SGS are situated. The groundwater rise beneath the ridge had a maximum relief of about 0.30 m during the time of the study.

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3.2 Groundwater chemistry

The water level elevations obtained in each well, which were used to draw the equipotential line and groundwater flow in Fig. 2, correlated significantly with the spatial distribution of the chemical species; apart from total phosphorus and ammonium which showed a different pattern (Table 2). The α level for the statistical significance was set at 0.05 using the Systat 12 software (Systat Software, Inc. Chicago, IL, USA). Water level had significant and negative relationship with EC ($r = -0.59$) and TC ($r = -0.64$) but a positive relationship with NO_3-N ($r = 0.67$) and NO_2-N ($r = 0.54$). Wells with high water level had high concentration of nitrate-nitrogen or nitrite-nitrogen. The lower concentration of the nitrate-nitrogen is associated with the wetlands and the high concentrations are associated with the beach ridge (Fig. 3). Nitrate-nitrogen showed positive and significant relationship with nitrite-nitrogen ($r = 0.96$; Table 2) since their formation from each other depends on the existing redox condition. Nitrate-nitrogen and nitrite-nitrogen showed significant but inverse relationship with temperature as indicated in Table 2. The spatial distribution of the total phosphorus showed a different pattern compared to the nitrate-nitrogen. Total phosphorus had a higher concentration in the wetlands while lower concentration were measured from samples collected from the beach ridge, apart from Wells FLE and FLW which had high concentrations of total phosphorus (Fig. 4). The spatial distribution of nitrate-nitrogen and total phosphorus at the site could be influenced by the season the groundwater samples were collected for analysis. The electrical conductivity measured depended significantly on the total carbon, total phosphorus, and ammonium concentrations.

3.3 Statistical analysis

3.3.1 Descriptive statistics

The measured temperature from the wells varied from 9.9 °C in Well SPS to 17.1 °C in Well NWW and the POND. The temperature variation was influenced by the season

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the samples were taken. The low temperature measured at Well SPS had to do with temperature variations, interaction with atmospheric temperature, and/or the infiltration of water with different temperature regime from the surface. This also accounted for the high concentrations of nitrate-nitrogen and nitrite-nitrogen in Well SPS.

The measured concentration of total phosphorus ranged from 0.02 to 19.2 $mg\,L^{-1}$, with a mean concentration and standard deviation of 2.66 and 6.25 $mg\,L^{-1}$, respectively. The lowest total phosphorus concentration was measured from the groundwater sample collected from Well SPS, which is located on the beach ridge while the highest concentration was measured from the groundwater collected from the POND. The POND was characterized by high electrical conductivity (2380 $\mu S\,cm^{-1}$) and total carbon concentration (373.8 $mg\,L^{-1}$), and an odorous smell of ammonia. The high concentration of ammonium and low concentration of nitrate-nitrogen or non detected concentration of nitrite-nitrogen could be an indication of dissimilatory nitrate reduction to ammonium and/or denitrification.

Isotopic analysis of nitrogen and oxygen in dissolved nitrate obtained in the groundwater samples collected from Wells FLE, FLW, and G08 indicated heavy signatures of the isotopes. FLE, FLW and G08 had $\delta^{18}O_{NO3}$ values of +30.8, +27.9, and +23.0 ‰, respectively; and $\delta^{18}N_{NO3}$ values of +42.22, +29.38, and +33.27 ‰, respectively. The values obtained for $\delta^{15}N_{NO3}$ is consistent with values obtained by Komor and Anderson (1993) in their study of nitrogen isotopic composition of nitrate from a feedlot; where the enriched nitrogen isotope was a result of denitrification and/or dissimilatory nitrate reduction to ammonium. $\delta^{15}N_{NO3}$ values greater than +10 ‰ are associated with nitrate obtained from human or animal waste (Seiler, 1996) as compared to the fertilizer used in the feedlot reclamation. Enrichment of $\delta^{18}N$ and $\delta^{18}O$ in nitrate within groundwater is an indication of denitrification (Böttcher et al., 1990; Kendall and Aravena, 2000).

Well SPN is located within an area that was recently excavated and refilled with medium- to fine-grained sand obtained from another location. This contributed to the lowest EC and the relatively high pH values measured from Well SPN. The recently

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excavated and refilled area is characterized by sparse vegetation, which could be a factor in the low total carbon measured within the groundwater sample obtained from Well SPN.

3.3.2 Cluster and factor analyses

The ten (10) sampling sites are categorized into three (3) clusters using the hierarchical cluster analysis. The first cluster is made of SPN, FLE, FLW, DVPT, and G08; the second cluster is made up of SGN, SPS, NWW, and SGS; and the last group is made up of only the POND (Fig. 5). The POND is considered as an outlier since the distance of its linkage is greater than that of the other clusters. The POND has a linkage distance of 300 as compared 150 for the others. There is a relationship between the clusters and the locations of the wells. Apart from Wells SGN and SPS, which were interchanged, the first cluster is associated with the beach ridge (recharge areas) while the second cluster is associated with the wetlands (discharge area).

Factor analysis of the chemical species was done to distinguish between the minimal and maximal nutrient impacted areas. Using the factor analysis, eigenvalues greater than 1 were used for the analysis because they contributed over 92 % of the total variance in the data (Table 3). The first, second and third eigenvalues values were used for the factor analysis because they were greater than 1 and also reflected high heterogeneity in the data distribution. From the factor analysis, chemical and physical parameters with factors loadings greater than 0.5, were considered to be the main cause of variability. Factor 1 accounted for 77.5 % of the total variation in the data, and was primarily composed of EC, NH_4^+, TC, and TP. This was represented by the sum of conductivity, ammonium, total carbon, and total phosphorus. Within factor loadings 2, pH, T, NO_3-N and NH_4^+ accounted for 82.8 % of the variability. This was represented by the ratio of the sum of ammonium, nitrate-nitrogen, and pH to temperature. The low value of nitrate-nitrogen and high values of ammonium in Factor 1 and the high values of nitrate-nitrogen and ammonium in Factor 2 could be due to the fluctuation in the nitrate-nitrogen caused by decrease in water level, reduced redox condition,

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presence of organic matter, and the high rate of denitrification and/or the dissimilatory nitrate reduction to ammonium occurring at the site. After rotating the data, the rotated loading matrices were similar to that of the component loadings but there was a slight variation. In Factor 1, more than 91 % of the variation was caused by the combination of EC, NH_4^+, TC, and TP, while Factor loading 2 had variations as a result of the ratio of temperature to the combination of pH and nitrate-nitrogen, with minor contribution from total carbon and ammonium.

The factor analysis showed a trend in the data. The physical and chemical species analyzed had a Pearson product-moment correlation coefficient of 0.99, indicating they are from the same source (manure). There is no significant contribution of nutrients from the bedrock because the bedrock is more than 60 m below the surface. The factor analysis grouped the data into three groups, similar to that of the cluster analysis (Table 5 and Fig. 6). Clusters 1, 2, and 3 in Fig. 5 corresponded with the minimal, intermediate, and maximal concentrated areas respectively.

4 Conclusions

Multivariate statistical analysis was used to analysis the distribution of nutrients within groundwater at an abandoned feedlot. Cluster and factor analyses divided the collected samples into three different clusters, which corresponded with minimal, intermediate, and maximal concentration areas. The spatial distribution of nitrate-nitrogen was influenced by water level, redox conditions, nitrite-nitrogen concentration, and the amount of organic carbon at the site. The results of the cluster and factor analyses corresponded with chemical species concentrations, especially nitrate-nitrogen within the study. The beach ridge had a relatively high nitrate-nitrogen concentration as compared to the wetland areas. The phosphorus concentration was relatively low on the beach as compared to the wetland zones. The wetlands were characterized by well grown cattails (*Typha latifolia L.*). Cattails in wetlands with high nutrient concentrations do very well compared to other species of Typhia (Grace and Harrison, 1986; Ciria et al., 2005).

Careful site selection and natural design of feedlot facilities can help mitigate off-site transport of nutrient. Harvesting and recycling of vegetative biomass may also aid in reducing nutrients concentrations within vegetated areas, especially wetlands.

This study indicates that multivariate analysis can be a good tool in examining the distribution of nutrients or contaminants. It can also be used as a predictive tool in explaining the movement of contaminants in soils, surface water, and groundwater.

Acknowledgements. This manuscript is part of the PhD research of the first author supervised by Phil Gerla. The authors of this manuscript would like to acknowledge the Plains and Prairie Potholes Landscape Conservation Collaborative (PPP-LCC), the US Geological Survey, the US Fish and Wildlife Services, the North Dakota View, and the Alan Cvancara Graduate Field Research Scholarship for their financial support in the research and publishing the manuscript. The authors of this manuscript would like to acknowledge the constructive comments and thorough reviews of the editor and the anonymous reviewers.

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Table 1. Location, water level, and concentration of the physical and chemical species of the groundwater in each well with their descriptive statistics.

Well	Easting (UTM)	Northing (UTM)	WL	pH	EC	*T*	TC	NO_2-N	NO_3-N	TP	NH_4^+
DVPT	700891.82	5289498.09	331.68	7.32	801	16.2	87	0.4	8.5	ND	0.20
FLE	701118.00	5289716.00	331.61	7.49	504	16.2	86	0.1	3.5	1.48	0.09
FLW	700816.15	5289428.71	331.68	7.41	584	16.3	79	0.1	7.0	1.56	0.16
G08	701304.46	5289721.56	331.62	7.20	832	16.0	113	–	6.7	0.15	0.04
NWW	700777.00	5289572.00	330.85	6.99	1372	17.1	331	ND	0.1	0.03	0.01
POND	700907.00	5289426.00	331.12	7.60	2380	17.1	374	ND	0.1	19.2	0.44
SGN	700887.49	5289731.59	330.75	7.33	1204	16.2	113	ND	ND	1.56	0.02
SGS	701128.60	5289554.13	331.12	7.23	1654	16.7	279	ND	1.4	0.09	0.01
SPN	700962.20	5289611.79	331.66	7.92	264	15.9	36	0.1	2.5	ND	0.01
SPS	700954.00	5289498.00	331.70	7.52	1420	9.90	153	0.7	19.2	0.02	0.18
Descriptive statistics of the water level and concentration of the physical and chemical species measured											
			WL	pH	EC	*T*	TC	NO_2-N	NO_3-N	TP	NH_4^+
Minimum			330.75	6.99	264	9.9	36	0.1	0.1	0.02	0.01
Maximum			331.70	7.92	2380	17.1	373	0.7	19.2	19.20	0.44
Mean			331.38	7.40	1102	15.7	165	0.2	4.7	2.66	0.12
Standard Deviation			0.38	0.25	634	2.1	118	0.2	6.2	6.25	0.14

All the physical and chemical species are in $mg\,L^{-1}$ except electrical conductivity (EC) which is in $\mu S\,cm^{-1}$, temperature (*T*) is in °C, and pH is unitless. Water level (WL) is in meters. Easting and northing are in meters. TC, TP, and ND represent total carbon, total phosphate, and non-detected, respectively. TC, NO_2-N, NO_3-N, TP, and NH_4^+ had a detection limit of 0.1, 0.1, 0.1, 0.01, and 0.01 $mg\,L^{-1}$, respectively.

Table 2. Pearson's correlation coefficient between the chemical species, physical parameters and water level.

	EC	NH_4^+	NO_2-N	NO_3-N	PH	*T*	TC	TP	WL
EC	1.00								
NH_4^+	*0.53*	1.00							
NO_2-N	−0.07	0.24	1.00						
NO_3-N	−0.15	0.17	*0.91*	1.00					
PH	−0.23	0.30	0.21	0.12	1.00				
T	−0.01	−0.08	*−0.87*	*−0.89*	−0.24	1.00			
TC	*0.89*	0.36	−0.28	−0.36	−0.38	0.23	1.00		
TP	*0.68*	*0.83*	−0.25	−0.31	0.28	0.25	*0.58*	1.00	
WL	*−0.59*	0.14	*0.54*	*0.67*	0.45	−0.41	*−0.64*	−0.25	1.00

EC, *T*, TC and TP represent electrical conductivity, temperature, total carbon and total phosphate, respectively. Italic values indicate significant correlation at 95 % confidence level.

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Table 3. Eigenvalues of the correlation matrices and the total variance of the data.

Component	Eigenvalues	Cumulative Eigenvalues	Total variance (%)	Cumulative (%)
1	*3.090*	3.090	44.137	44.137
2	*2.037*	5.127	29.096	73.232
3	*1.336*	6.463	19.083	92.315
4	0.412	6.875	5.885	98.200
5	0.078	6.953	1.114	99.314
6	0.035	6.988	0.500	99.814
7	0.013	7.001	0.186	100.000

The italic values are eigenvalues greater than 1, which forms more than 92 % of the variance in the data.

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Table 4. Factor loadings for factor 1 and 2.

Variable	Component Loadings			Rotated Loading Matrix		
	F1	F2	Communality	F1	F2	Communality
EC	*0.870*	0.184	0.791	*0.882*	0.119	0.792
NH_4^+	*0.654*	*0.623*	0.816	*0.825*	−0.367	0.815
NO_3-N	−0.458	*0.781*	0.820	−0.168	*−0.890*	0.820
PH	-0.112	*0.526*	0.289	0.072	*−0.532*	0.288
T	0.380	*−0.800*	0.784	0.089	*0.881*	0.784
TC	*0.869*	−0.107	0.767	*0.783*	0.393	0.768
TP	*0.885*	0.277	0.860	*0.926*	0.036	0.859

The italic values are values that accounted for the variability within the data set. F1 and F2 represent factor 1 and 2, respectively.

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Table 5. Factors used in plotting the clusters.

Division	Component Loadings Well	F1	F2	Rotated Loading Matrix F1	F2
	SPN	265	38	263	53
Minimal	FLE	518	78	515	101
	FLW	581	96	579	105
	DVPT	774	136	775	132
	G08	824	137	823	148
	SGN	1152	201	1154	198
Intermediate	SPS	1363	256	1371	217
	NWW	1487	207	1471	304
	SGS	1687	266	1679	316
Maximal	POND	2418	394	2412	442

F1 and F2 represent factor 1 and 2, respectively.

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Nutrients in groundwater near an abandoned feedlot

P. Gbolo and P. Gerla

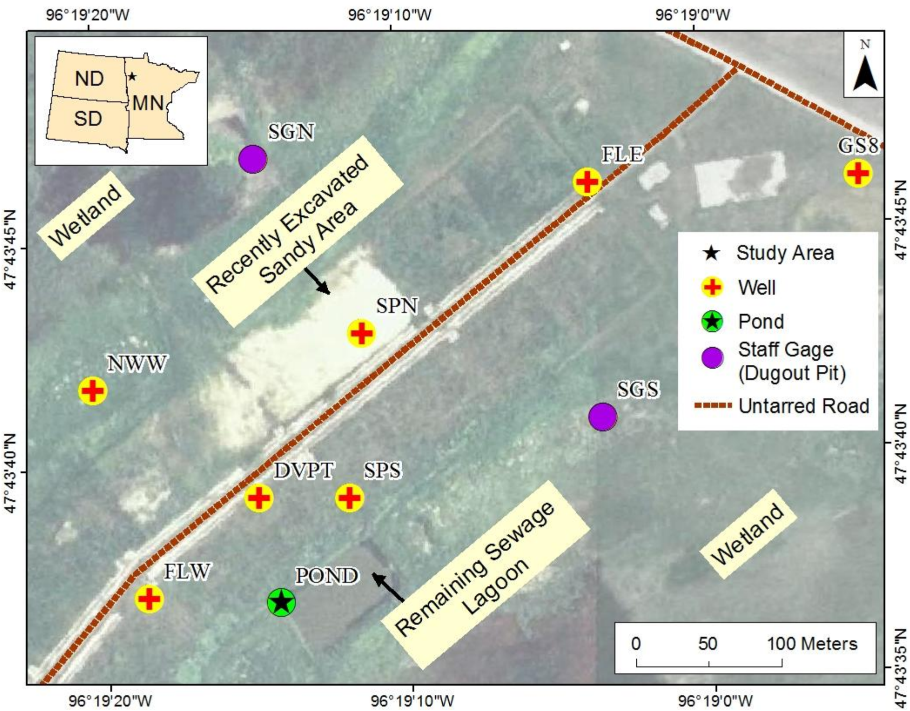

Fig. 1. Map of the study area showing the sampled wells and the wetland areas.

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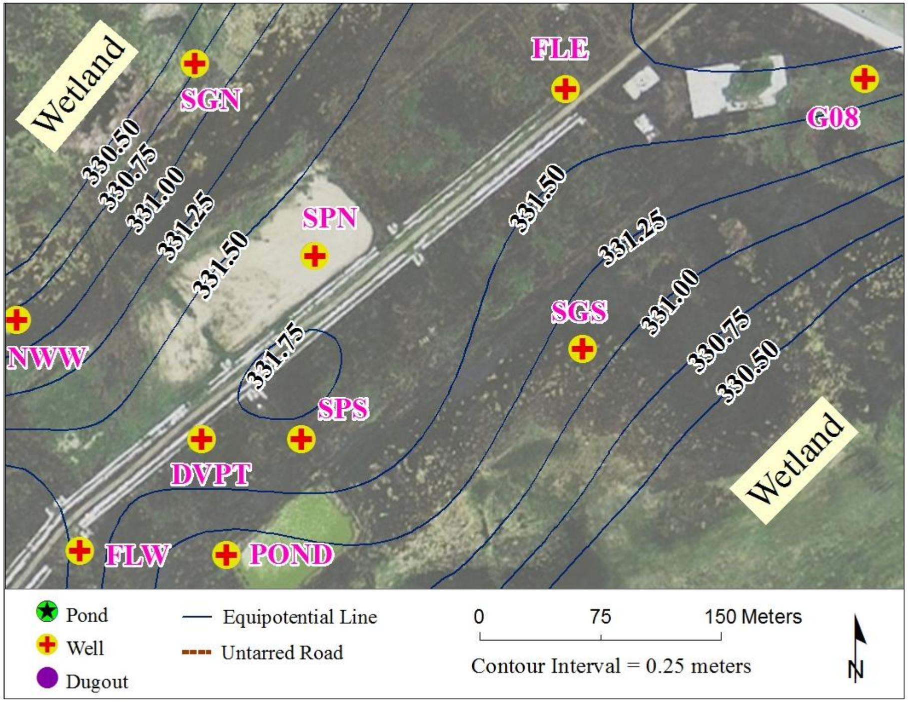

Fig. 2. Potentiometric map showing the longitudinal flow of groundwater for fall 2010.

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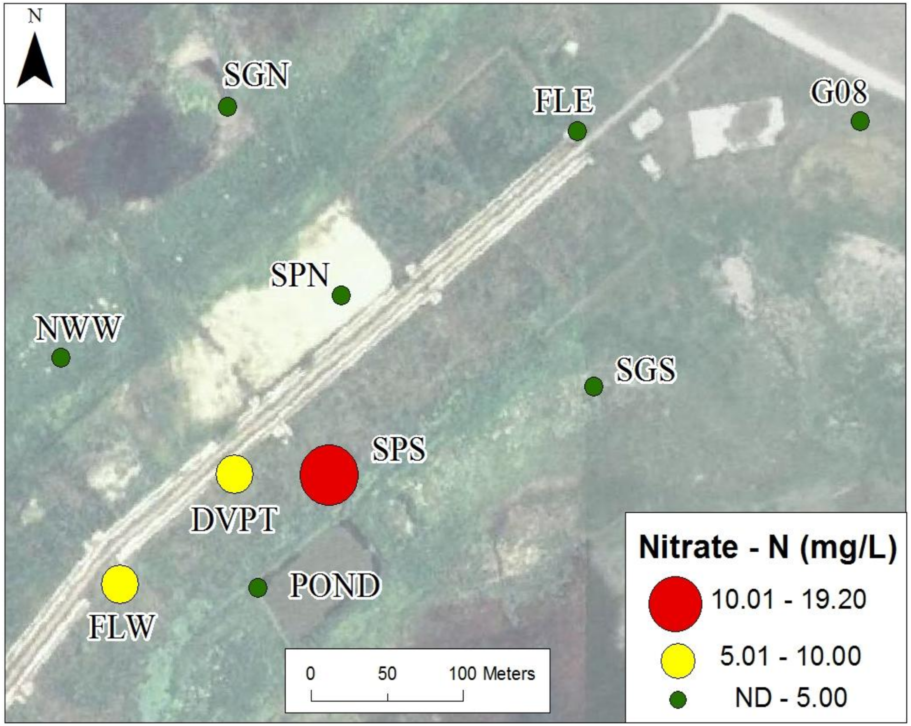

Fig. 3. Nitrate-nitrogen concentration within the wells.

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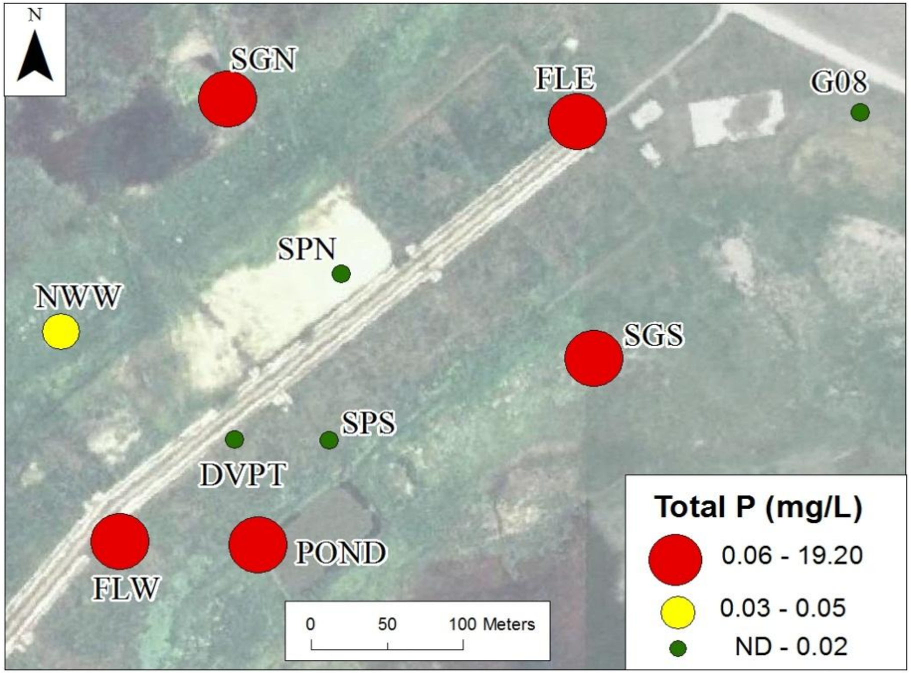

Fig. 4. Spatial distribution of total phosphorus concentrations within the wells.

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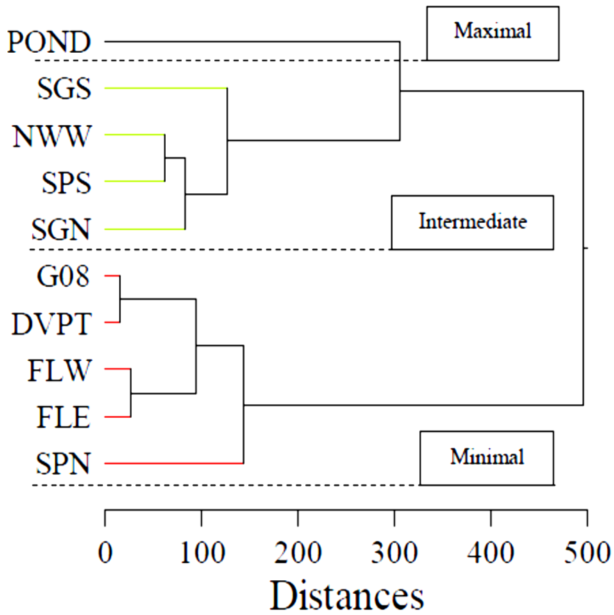

Fig. 5. Dendrogram showing the clustering of the data collected from the 10 wells.

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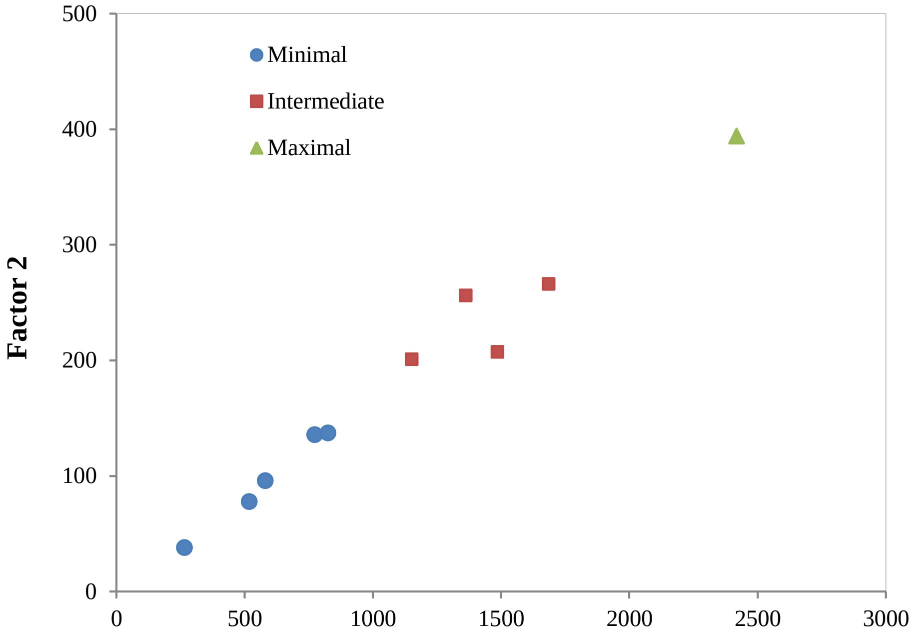

Fig. 6. Scatter plot of the first two factors showing three clusters.

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