SITE-SPECIFIC ENVIRONMENTAL RISK ASSESSMENT FOR PHOSPHORUS RUNOFF

by

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MINI-DISSERTATION

Submitted in (partial) fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE)

in the

FACULTY OF SCIENCE AND AGRICULTURE

(School of Agricultural and Environmental Sciences)

at the

UNIVERSITY OF LIMPOPO

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2014

DECLARATION

I declare that **SITE-SPECIFIC ENVIRONMENTAL RISK ASSESSMENT FOR PHOSPHORUS RUNOFF** hereby submitted to the University of Limpopo, for Master of Science in Agriculture (Soil Science) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Nomagugu Precious Lukhele	May 2014
Names	**Date**

ACKNOWLEDGEMENTS

Firstly, I would like to honour God, my heavenly father for strength He gave me to complete this degree.

I would like to express gratitude to my supervisor, Dr M.E. Moshia for his encouragement, guidance and constructive criticism in the course of this research and preparation of this manuscript. I have learnt invaluable lessons through his scientific insights and assistance throughout the lifecycle of this project.

I gratefully extend my thanks to my co-supervisor, Dr. P. Shaker for her guidance, patience and support during the course of this research. I am thankful for her scientific insights and suggestions for the improvement of this manuscript.

I would also like to extend my gratitude to the HOD of the department, Dr F.R. Kutu for his concern, constant encouragement and support.

I extend my appreciation to Suzan Mashego, my fellow graduate student, my friend and sister. Your determination, perseverance and passion for research have motivated me to extend myself in order to complete my studies. Sue, thank you for the constant support and encouragement. I thank God for you.

I extend my deepest gratitude to my mentor at the Department of Agriculture, forestry and fisheries, Mr Ndifelani Mararakanye. I believe you were God sent. Thank you for your scientific insight and teaching me all the GIS I know. You have also taught me that knowledge is meant for sharing and through your guidance I have become a better researcher.

I acknowledge the National Research Foundation (NRF) for providing me with a postgraduate scholarship. Without the financial assistance I received from NRF, this study would not have been completed.

Finally, I would like to extend my sincere gratitude to my parents, Martin and Samaria Lukhele, my brother, Melusi and my sister, Debbo. I thank you for your constant support, encouragement and prayers for my success. Through the faith you have in me, I have been able to extend myself and do things and reach for goals I thought were too high to reach. Thank you for not allowing me to give up. May God bless you in every way possible.

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ABSTRACT

Phosphorus (P) runoff from agricultural sites and the subsequent loading into surface water bodies contribute to eutrophication. Environmental concerns associated with P loading in soil have motivated the need for the development of a proper tool that will allow farmers to identify agricultural areas or management practices that have the greatest potential to accelerate eutrophication. The objective of the study was to determine the spatial variability of soil test P, soil loss potential of the farm, P application rate and methods, and map P runoff risk across the field. This study was conducted in Vierfontein Boerdery in Kriel, Mpumalanga province, South Africa (longitude 29.11258833 and latitude -26.27104340). The field was under dryland cultivation and planted to yellow maize that was rotated with soybeans. Soil samples were taken at georeferenced locations in a 100 x 100 m grid for soil analysis. Spatial layers of soil P distribution, soil loss potential as well as application rate and method were created in ArcGIS software. These layers were used as input factors in a P index model to identify areas in the farm that are vulnerable to P runoff. Results indicated a variation in soil test P. Although soil test P variation was not statistically different at $P \leq 0.05$, variation had both agronomic and environmental implications. This variation could be attributed to differences in site-specific conditions and management practices. Furthermore, soil loss potential across the study site predicted by the Revised Universal Soil Loss Equation (RUSLE) showed variation with a range of 3-15 tons/ha/yr. This variation was attributed to differences in topographic variations in the study site. There is a need for best management practices that control soil erosion to minimize P runoff into water bodies.

KEYWORDS: Eutrophication, Geographic Information System, Phosphorus best management practises, Phosphorus runoff index, Soil erosion, Site-specific management

CHAPTER 1: INTRODUCTION

1.1 Background

The significance for this research lies in the reports from the South African Council for Scientific and Industrial Research (CSIR) that stated that more than 40 percent of South Africa's dams suffer eutrophication. Without radical improvement in eutrophication management approaches and treatment technologies, eutrophication will continue to decrease the benefits and increase the costs associated with the use of water resources (Oberholster and Ashton, 2008). Environmental concerns arising from Phosphorus (P) loading in soil have motivated the need for the development of a proper tool that will allow farmers to identify agricultural areas or management practices that have the greatest potential to accelerate eutrophication. The P environmental risk assessment tool will be used to gauge the P loading in the soil and the degree of runoff risk resulting from annual application of organic fertilizers, i.e. animal manure on agricultural fields.

1.2 Rationale

Phosphorus runoff from agricultural sites and the subsequent loading into surface water bodies contribute to eutrophication. The significance for this research lies in the reports from the South African CSIR that stated that more than 40 percent of South Africa's dams suffer eutrophication. Without radical improvement in eutrophication management approaches and treatment technologies, eutrophication will continue to decrease the benefits and increase the costs associated with the use of water resources (Oberholster and Ashton, 2008). Environmental concerns arising from P loading in soil have motivated the need for the development of a proper tool that will allow farmers to identify agricultural areas or management practices that have the greatest potential to accelerate eutrophication. The P environmental risk assessment tool will be used to gauge the P loading in the soil and the degree of runoff risk resulting from annual application of organic fertilizers, i.e. animal manure on agricultural fields. Although point sources such mines, industrial and urban effluents are usually the main contributors of P polluters into receiving water bodies, agriculture was implicated as a significant non-point source contributor to eutrophication (Van der Laan, 2009). As such, it is important that the agricultural community take the initiative to minimise P runoff and the subsequent loading into surface water bodies in order to reduce impact on water quality. This can be achieved through modeling of specific field portions that have high P runoff potential. Following that, these field portions can be prioritized for appropriate nutrient and soil management practices.

1.3 Motivation of the study

Environmental concerns associated with P loading in soil have motivated the need for the development of a proper tool that will allow farmers to identify agricultural areas or management practices that have the greatest potential to accelerate eutrophication. The P environmental risk assessment tool will be used to gauge the P loading in the soil and the degree of runoff risk resulting from annual application of organic fertilizers, i.e. animal manure on agricultural fields.

1.4 Purpose of the study

1.4.1 Aim

The aim of this study was to assess the risk of phosphorus runoff at Vierfontein farm using phosphorus environmental risk assessment tool within a Geographic Information System (GIS) framework in order to recommend site specific best management practices that can minimise P runoff.

1.4.2 Objective of the study

To determine the spatial variability of soil test P, soil loss potential of the farm, P application rate and methods, and map P runoff risk across the field.

1.4.3 Hypothesis

Soil test P does not vary spatially across the field, and there is no risk of P runoff on this agricultural field, and therefore there is no need for variable rate P applications.

CHAPTER 2: LITERATURE REVIEW

This chapter is a review of studies on the factors that contribute to P runoff from agricultural sites. It also describes the consequence of P runoff on water quality. This chapter further reviews site-specific nutrient management and best management practices that are practices that can be explored in managing the risk of P offsite movement.

2.1 Introduction

Phosphorus is an indispensable macronutrient for plant growth. This macronutrient is involved in many plant metabolic reactions, ranging from respiration to formation of plant genetic encoding instructions and energy production in support of plant growth (Brain *et al.*, 2001). For this reason, P is widely applied to cultivated agricultural fields as inorganic fertilizers (e.g. rock phosphate, calcium orthophosphates and ammonium phosphates), and organic fertilizers (e.g. animal manures, and treated municipal sewage) to achieve optimum crop yields (Penn, 2004). Globally, the crop production and soil fertility management communities, which include farmers and researchers, are aware of the advantages of maintaining proper soil P fertility through the application of these fertilizers. However, long-term applications of both organic and inorganic fertilizers have resulted in some cases where soil P levels are greater than agronomic recommendation for optimal crop yields (Mikkelsen, 1997; Sims *et al.*, 2002; Guffre *et al.*, 2004).

While excess P was reported to indirectly affect plant growth by reducing plant uptake of other nutrients such as iron, manganese, and zinc, it can also be carried off-site in runoff water (Cahn *et al.*, 1994; Fairhurst *et al.*, 1999). Phosphorus that is carried in runoff water can potentially contaminate surface water bodies by elevating P concentration in water above critical levels for aquatic plant growth and consequently enhance eutrophication (Cahn *et al.*, 1994; Toth *et al.*, 2006). This has led to the development of P index in developed countries for the assessment of risks associated with P transport from agricultural sites (Lemunyon and Gilbert, 1993). The use of P Index provides means of identifying fields that have P runoff potential. Areas with high P runoff potential will require additional conservation practices and limitations of manure or fertilizer P application (Jokela, 1999).

2.2 Soil P accumulation

Historically, animal manure were applied to cropland as a means of disposal, nutrient and organic matter recycling, topsoil quality improvement, and crop productivity increase (Bassaletti, 2005). Long-term application of animal manure to agricultural fields has caused an excessive accumulation of P in soils. When animal manure is applied annually on agricultural fields based on crop N requirements, more P is applied than is required by crops. This annual application of animal manure on agricultural soils most often results in P accumulation because crops generally use small amounts of P relative to N (Mikkelsen, 1997). This Application of animal manure based N requirements of crops has led to P applications in excess of crop removal, soil P over-accumulation, and increased risk of P loss in runoff (Kellogg and Lander, 1999).

2.3 Phosphorus Runoff from agricultural fields

The largest pool of P in a field is the soil itself (Snyder *et al.*, 1999). Phosphorus reacts with soil minerals and tends to stay tightly associated with the soil mineral surfaces. As such, the major loss of P is by plant removal, erosion of topsoil and runoff (Bacon, 2010). Soil slope and surface conditions, tillage practice as well as soil type may influence P runoff (Havlin *et al.*, 1999). Phosphorus runoff can also further be influenced by the rate and timing of fertilizer application, method of application and form of fertilizer used (McDowell *et al.*, 2001). In manured or fertilized fields, the concentration of P in surface runoff increases with the application rate, the amount of applied P remaining on the soil surface, and the solubility of the applied P (Farmers guide to agriculture and water quality issues, 2003).

In South Africa, two approaches of P fertilization are generally followed. The first approach involves P application in excess of seasonal crop demand to build up P status of the soil (Farina and Channon, 1987), while the second approach alters fertilizer application according to anticipated or targeted crop yields for the season (Henry and Smith, 2004). Advantages of the first approach include positive effect of a good soil P reserve on crop yield and protection from the negative effects of inflation on production costs (Henry and Smith, 2004). A disadvantage is the increase of P runoff potential from soil (Van der Laan, 2009).

2.4 Eutrophication

Although the benefits of P on agricultural production are evident, this element can be a pollutant if it moves from agricultural fields into surface water bodies (Wood *et al.*, 1998). The enrichment of surface water bodies with P inputs from agricultural fields can cause accelerated eutrophication (Sharpley *et al.*, 1994; Lory, 1999). According to Leytem *et al.* (1999), eutrophication is a process of excessive algal growth in surface water as a result of nutrient enrichment. When P is in adequate quantities in fresh water, algae growth accelerates because P is frequently the limiting factor in the growth of algae (Lory, 1999). This excessive aquatic plant growth and subsequent microbial breakdown of dead aquatic plant material results in the depletion of dissolved oxygen, changes in plant species and food chain effects, and the release of toxic water soluble neuro- and hepatoxins (Sharpley *et al.*, 1994; Sharpley and Rekolainen, 1997). This process of eutrophication also negatively affects fisheries, recreation, industry and drinking water quality. South African river systems that are classed as eutrophic or having the potential to become eutrophic in the near future due to their poor water quality are the Olifants, Vaal, Crocodile, Mgeni, Orange, Modder and the Buffalo rivers (Pieterse and Van Vuuren, 1997; Walmsley, 2000).

2.5 Phosphorus index

Knowledge of soil P levels is an essential component of nutrient management planning for crop production. These soil P levels are used directly or as a component of P indices to assess the risk of P loss from fields to surface water bodies (Mallarino *et al.*, 2002). In recent years, increased attention was focused on models for risk assessment of source areas in agricultural landscapes. Among the simplest of such models are environmental risk assessment indices, which have been developed particularly for P and to some extent N (Sharpley and Rekolainen, 1997). Phosphorus environmental risk assessment index method is the best way to select fields most suitable for manure application. Phosphorus index is intended to serve as a practical screening tool for use by extension agents, consultants, and farmers to identify agricultural areas or management practices that have the greatest potential to accelerate eutrophication (Lemunyon and Gilbert, 1993). As such, P index identifies alternative management options available to land users, providing flexibility in developing remedial strategies (Sharpley *et al.*, 1993).

2.5 Site-specific management of phosphorus

Soil properties may vary greatly across space and time depending on soil types, topography, climate, vegetation and anthropogenic activities, all of which affect the spatial distribution patterns of soils (Mallarino *et al.*, 2002; Wenjiao *et al.*, 2009). This change of soil properties can lead to variability in soil P available for plants by influencing total amount of P, the fraction available to crops and potential loss in agricultural runoff (Mallarino *et al.*, 2002). Soil fertility studies have demonstrated with a few exceptions, large within–field variability of soil test P and fertilizer need (Mallarino and Wittry, 2000). For that reason, uniform management of crops under spatially variable conditions can result in less than optimum yields and as well as excessive fertilizer applications that may potentially reduces environmental quality (Yasrebi *et al.*, 2008).

Variability within fields has amplified the need for site-specific nutrient management. Site-specific nutrient management has received considerable attention due to the three main potential benefits of increasing input efficiency, improving economic margins of crop production and reducing environmental risks (Redulla *et al.*, 1996). Sharma and Binda (2007) defined site-specific management as an information and technology based farm management system to identify, analyse and manage variability within fields for optimum profitability, sustainability and protection of land resources. In this mode of farming, new information technologies such as GIS and remote sensing can be used to make better decisions about many aspects of crop production (Auernhammer, 2001). Unlike the conventional P fertilizer management strategy that relies on the premise that soil P status and the production potential of a soil can be assessed over large areas, site-specific management of P gives farmers potential to apply the precise requirement of P at each given location in a field consequently reducing the risk of P runoff (Yasrebi *et al.*, 2008).

CHAPTER 3: RESEARCH METHOLOGY

This chapter describes the methodology followed in order to achieve the objectives mentioned in chapter one. In order to meet the ultimate goal of deriving the Phosphorus (P) runoff potential map, various data were collected and analysed within a Geographic Information System (GIS). The description of the study area is provided first, followed by the methodology used to determine the spatial distribution of P. The method used to determine the distribution of the chemical and physical properties of the collected soil data is explained in this chapter. The source of the soil loss map and the description on how the dataset was created is also described. The process of determining the P application rate and methods is also discussed. Finally, the process of modelling P runoff risk of the site is described.

3.1 Description of the study area

The study was conducted at Vierfontein Boerdery farm located at Kriel in Mpumalanga Province of South Africa (Fig. 3.1). The farm is located at longitude 29.11258833 and latitude -26.27104340. The surrounding land use of the area is mainly mining and according to the farmer; some portions of the farm are currently being mined for Coal. The Rietspruit River flows through the farm and drains into the Olifants River. Though the climate of the area is classified as semi-arid, the area receives heavy rainfall in the summer months averaging to 771 mm/annum. The average temperature in this region during the crop growing season is 20^0C, with average minimum temperatures of 16.2^0C and average maximum temperatures of 23.8^0C. For the purpose of this study, two cultivated fields (Haasfontein fields) in the farm were digitised in ArcGIS 10 with SPOT 5 satellite imagery on the background. The size of the fields is 37.6 and 37.2 ha respectively. The fields are planted to yellow maize for a continuous period of three years and in every fourth year, soya beans are cultivated. According to the farmer, cattle are put to graze the fields after harvesting.

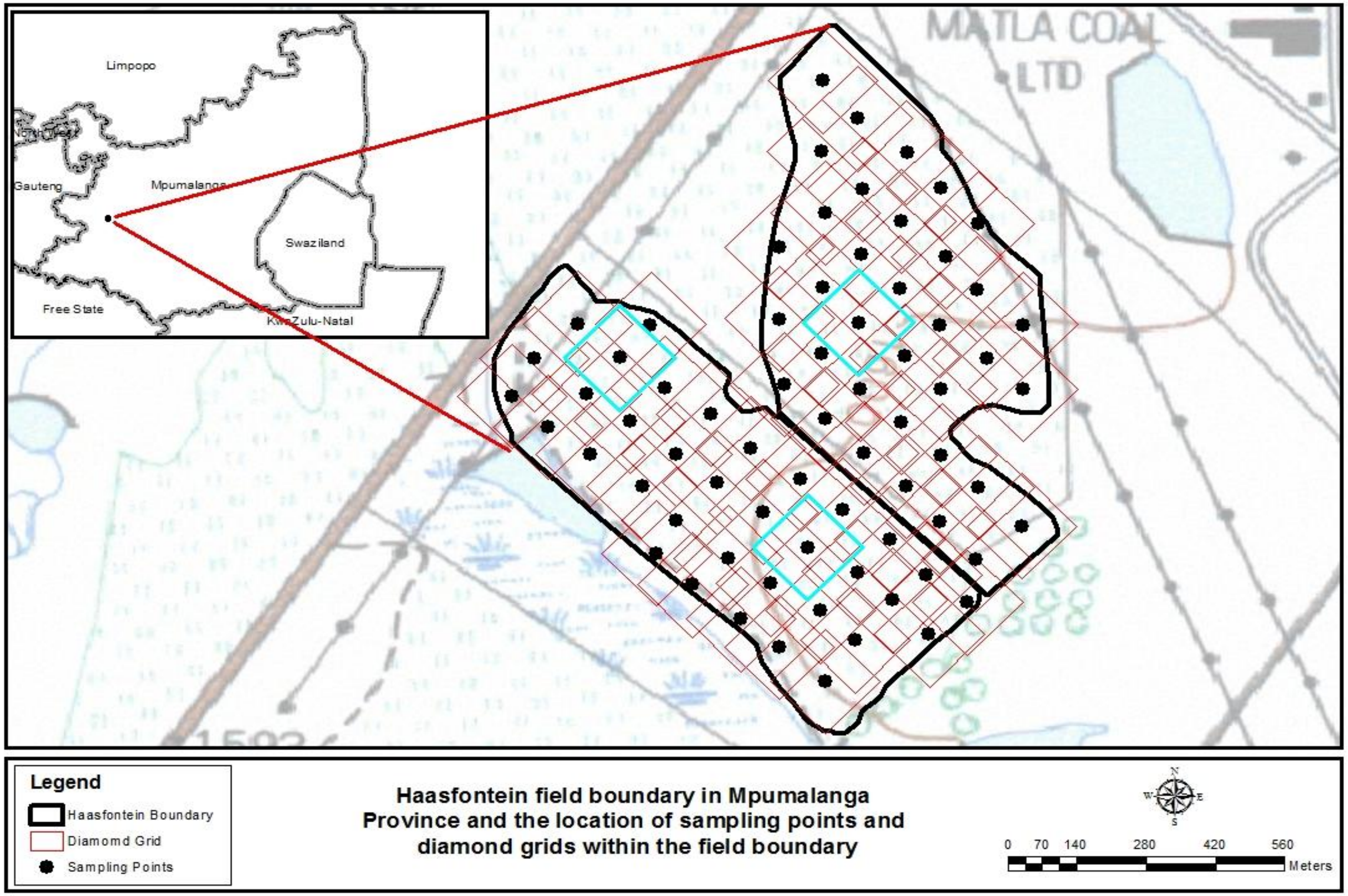

Figure 3.1 Map of the study location in Kriel, Mpumalanga Province, South Africa.

3.2. Determining the spatial distribution of Phosphorus

In order to determine the spatial distribution of P, a diamond grid of 100 X 100 m was generated over the two agricultural fields (Fig. 3.1). The diamond grid was generated using Hawths tool extension, developed by the United States Department of Agriculture, in ArcGIS 10 (Beyer, 2004). A centre point for each grid was generated for the purpose of data collection. A total of 70 points were generated and soil samples were taken at each point (Fig 3.1). Soils were sampled at a depth of 0-20 cm at geo-referenced centre locations and analyzed for pH (McLean, 1982), P (Bray and Kurtz, 1945), cation exchange capacity (CEC) (Barnard *et al.*, 1990), and particle size distribution (Gee and Bauder, 1986).

After soil analysis, P bray-1 values were interpolated in ArcGIS 10 using Inverse Distance Weight (IDW) technique. Interpolation is the procedure of predicting the value of un-sampled areas based on the analysis of measurements made at sampled points within the same area (Robinson and Metternicht, 2006). In this study, IDW was used to interpolate P spatial distribution and a power of 2 was used to determine the weight from distance.

The formula of this interpolation technique is

$$\hat{z}(s_0) = \sum_{i=1}^{n} \gamma_j Z(s_I) \quad \text{...} \quad (1)$$

where $z(s_0)$ is the estimated value for an un-sampled location s_0, n is the number of measured sample points surrounding the prediction location used for the prediction, λj is the weight for each measured point, and Z (si) is the observed value at location si. The resulting map was then classified into classes of 0-30 ppm, 30-60 ppm, 60-120 ppm and > 120 ppm.

3.3. Rill and Inter-rill Erosion

Rill and inter-rill erosion is the loss of soil along the hill slope caused by precipitation (Sharkoff *et al.*, 2008). For the purpose of this study, a spatial layer of the estimate soil loss for South Africa was obtained from the Ministry of Agriculture. This spatial layer was developed by Le Roux *et al.* (2008). In the development of the soil loss map of South Africa, principles and components of the Revised Universal Soil Loss Equation (RUSLE) were applied. This RUSLE model is used to indicate an average annual long-term movement of soil, thus potential for sediment and attached P movement toward a water body (Renard *et al.*, 1994). The RUSLE model groups the influences on erosion into five parameters, namely climate, soil profile, relief, vegetation and land use, and land-management practices (Le Roux *et al.*, 2008). The equation is,

$A = R.K.L.S.C.P$

where,

A is the spatial average soil loss in t/ha·yr

R is the rainfall runoff erosivity factor in MJ.mm/ha·h·yr

K is the soil erodibility factor in t/ha per unit R

L is the slope length factor

S is the steepness factor

C is the cover management factor

P is the support practice factor

The value reported is tons of soil loss per hectare per year (tons/ha/year). The soil loss potential map was classified into classes of <7.5 tons/ha/year, 7.5-12.5 tons/ha/year, and 12.6-25 tons/ha/year.

3.4. Determining the Phosphorus application rate and methods

The P application rate is the amount of phosphate (P_2O_5) annually applied to the field in kg/ha from both inorganic and organic sources (Sharkoff *et al.*, 2008). The P application rate and method information were obtained from the farmer. The application rate data was in a form of a hard copy map. The map was geo-referenced and digitised in ArcGIS 10.

3.5. Modelling Phosphorus risks areas

A compatible P runoff environmental risk assessment index model for semi-arid environment developed by Sharkoff *et al.* (2008) was used (Table 3.1). The Colorado P index was chosen for the purpose of this study because the climatic conditions in Colorado are similar to the climatic conditions in South Africa. Each input factor i.e. P distribution, soil erosion potential and application rate and methods was rated from low to very high based on this model as indicated in Table 3.1. The factor maps were reclassified in ArcGIS 10 based on the ratings of Table 3.1. The final P runoff potential map was derived in ArcGIS 10 using Spatial Analyst arithmetic expression. Table 3.2 was used interpret P runoff risks (Sharkoff *et al.*, 2008).

Table 3.1 Phosphorus risk assessment index

Factor	Low (1)	Medium (2)	High (3)	Very High (4)	Score
1. Runoff class	Low	Medium	High	Very High	
2. Soil test P (Bray 1)	30	30 – 60	61 – 120	>120 ppm	
3. P application rate annually applied Kg P_2O_5 /ha / year	0-14	15-41	42-68	>68	
4. P application method	No P is applied	Spring applied	Autumn or winter applied	Surface applied with no incorporation	
Gross Score (sum of Factors 1 through 4)					
5. BMP implementation credits	Subtract one point for each of the following BMPs implemented on this site: Cover or Green Manure Crops; Filter Strips; Polyacrylamides to decrease Irrigation-Induced Erosion, or; Contour Buffer Strips.				
Net Score (Sum of Factors 1 through 4 less Factor 5, BMP Implementation Credits)					

Table 3.2 Risk interpretation

Net score	Phosphorus runoff risk interpretation
‹8	This field has a low potential for off-site P movement if managed at the current level. Calculate organic nutrient application rates according to crop N requirements.
8-11	This field has a medium potential for off-site P movement. Consider management changes to decrease risk and support continued long-term organic nutrient applications. Calculate organic nutrient application rates according to crop N requirements.
12-15	This field has a high potential for off-site P movement. Implement management changes to decrease risk. Calculate organic nutrient application rates according to crop P requirements.
16	This field has a very high potential for off-site P movement. Implement management changes to decrease risk. Do not apply organic nutrients to this field without decreasing the risk for off-site transport.

3.6 Data analysis

Distribution of the data was described using descriptive statistics such as means, standard deviation (SD), coefficient of variation (CV), the maximum values, minimum values, skewness and kurtosis for soil test P, pH, K, Ca, Mg, CEC and Na from 35 sampling points (Littel *et al*., 2002). This analysis was conducted using Statistical Analysis System (SAS) software package.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter illustrates the findings of this study by means of a set of maps and tables. Further discussions of the implications of the results are presented. Foremost, descriptive statistics of measured soil chemical and physical properties are illustrated. Secondly, the results of the runoff risks factors i.e. P distribution, soil loss potential, slope percentage and application method and rate are presented. Ultimately, the results of the P runoff potential of the farm or site are presented.

4.1 Chemical and physical properties of the soil

Table 4.1 illustrates the descriptive statistics of measured chemical and physical properties of the soil in Haasfontein fields. Measured soil pH values showed significant variation at $P \leq 0.05$ and pH values ranged from 4.0 to 5.9 being classified from strongly acid to medium acid (Table 4.2; Brady and Weil, 2007). Based on the guidelines stated by Miles and Zenz (2000), the optimum soil pH for maize production is 5.5 - 7.5. Since pH levels of the soils in this study site were generally not suitable for maize production, it can be inferred that the buffer pH needs to be determined in order to establish lime requirement to correct the pH. While the study was about P runoff assessment, there was a need to assess pH as the form and availability of soil P is highly pH dependent (Williams *et al.*, 2010). Moreover, at low pH values, it is known that aluminium and/or manganese in soil solution can increase to toxic levels. This aluminium reacts more readily with phosphates forming aluminium phosphates (Brady and Weil, 2007).

Soil texture of the study site was determined to be Sandy clay loam. This type of soil is characterised by soil material that contains 20 to 35% clay, less than 28% silt, and 45% or more sand (Soil Survey staff, 1993). According to Sharpley and Rekolainen (1997), textural class is an important factor that determines the soil susceptibility to erosion. It is important to note that soil with relatively higher silt and clay content than coarser textured soils, like in the study site, has a greater erodibility (Aase *et al.*, 2001). Soil texture further has an important impact on Cation Exchange Capacity (CEC) since negatively charged colloids dominate in the clay-sized fraction (Ketterings *et al.*, 2007). This study site had a CEC range of 2.1 to 5.3 cmol (+).kg^{-1}. Lower CEC values indicate that a soil has a lower capacity to hold cations.

Table 4.1 Selected soil properties of 70 soils samples acquired at 0-20 depth at Haasfontein fields

Description	Soil Properties			
	pH	†CEC	† P	Soil textural Class
		cmol(+).kg^{-1}	mg kg^{-1}	Sandy Clay Loam
Mean	4.8	3.3	19.6	
Median	4.8	3.2	15.5	
Mode	5.0	3.3	13.0	
Std deviation	0.4	0.7	13.9	
Kurtosis	0.2	0.2	2.1	
Skewness	0.2	0.6	1.6	
Minimum	4.0	2.1	4.0	
Maximum	5.9	5.3	67.0	

†CEC is soil electrical conductivity

‡ P is Bray 1 soil phosphorus

Table 4.2 Analysis of Variance for pH

Source	**Df**	**Sum of squares**	**Mean Square**	**F**	**Sig.**
Between Groups	1	.825	0.825	7.410	*
Within Groups	68	7.573	0.111		
Total	69	8.398			

* Significant at the 0.05 probability level

Table 4.3 Analysis of Variance for Phosphorus

Source	**Df**	**Sum of squares**	**Mean Square**	**F**	**Sig.**
Between Groups	1	151.557	151.557	0.782	NS
Within Groups	68	13173.714	193.731		
Total	69	13325.271			

† NS is Non significant at the 0.05 probability level

4.2 Soil Phosphorus distribution

Soil test P (STP) concetration is one of the factors affecting the loss of P in runoff (Sharpely *et al.*, 1994). For this reason, spatial variability in STP levels across the field needed to be considered in assessing risk of P runoff. Fig. 4.2 shows the spatial distribution of STP across the study site. Measured P values ranged from 4 to 67 mg/kg with a mean of 19.6 mg/kg and a standard deviation of 13.9 (Table 4.1). According to Wortmann *et al.* (2005), spatial variation of P may result from differences in long-term soil forming processes, P fertilization and management practices. In the study site, there was an area where Bray 1 P values were as high as 67 mg/kg, this high value may be attributed to P enrichment from excreta depositions from beef cattle that are put in the farm to graze after harvesting.

While STP variation across the study site was not statistically significant (Table 4.3), variation in STP had important implications for agronomic and environmental P management (Gupta *et al.*, 1997). According to Westfall and Davis (2009), Bray 1 P is classified as follows for dry land maize production, 0-7 low, 8-35 medium, 36-39 high and >40 very high. Moreover, Westfall and Davis (2009) further reported the optimum P agronomic requirements for dry land maize production to be the range of 22-27 mg/kg. Based on these agronomic P requirements, 15% of the 74.8 ha fields was above the optimum agronomic requirements, and at this point, further P applications do not generate increases in yield but may increase the risk of P runoff (Fig. 4.1). On the other hand, 83% of the field had low Bray 1 P values for maize production and hence the need for additional P fertilization. This variation in Bray 1 P values suggests that there is a possibility for variable rate P fertilizer application. Variable fertilizer application has the potential benefits of increasing input efficiency, improving economic margins of crop production and reducing environmental risks (Yasrebi *et al.*, 2008).

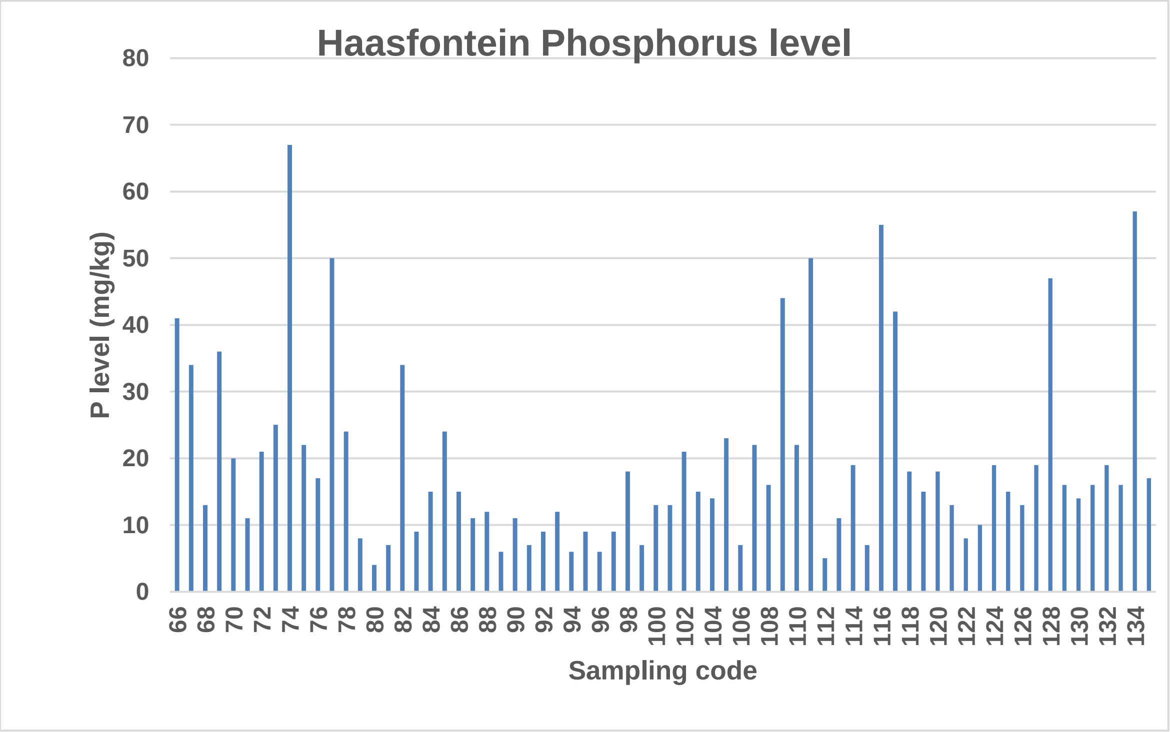

Fig. 4.1 Histogram of P from the 70 soil samples

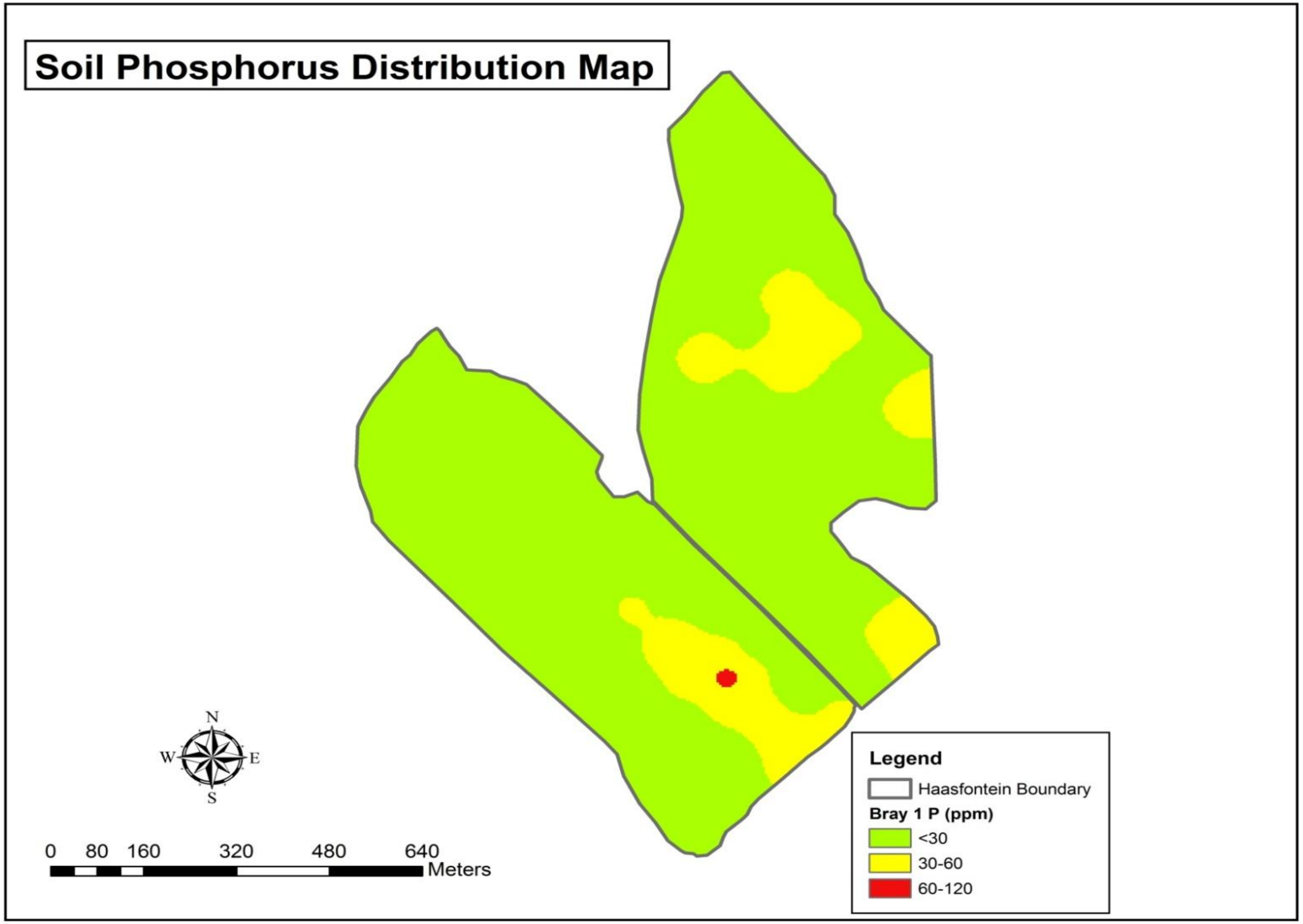

Fig. 4.2 Spatial distribution of Soil Test Phosphorus

4.3 Soil loss potential

A range of 3-15 tons/ha/yr of potential soil loss values was predicted by RUSLE for the study site. Over 80% (60 ha) of the study site had potential soil loss values lower than 7.5 tons/ha/yr (Fig. 4.3). Highest values of potential soil loss were calculated in the south western portion of the study site, meaning that, the western portion of the study site had a higher average annual long-term movement of soil. These trends in potential soil loss may be a result of topographic variations considering that high potential soil loss values coincided with high slope percentages (Fig. 4.4)

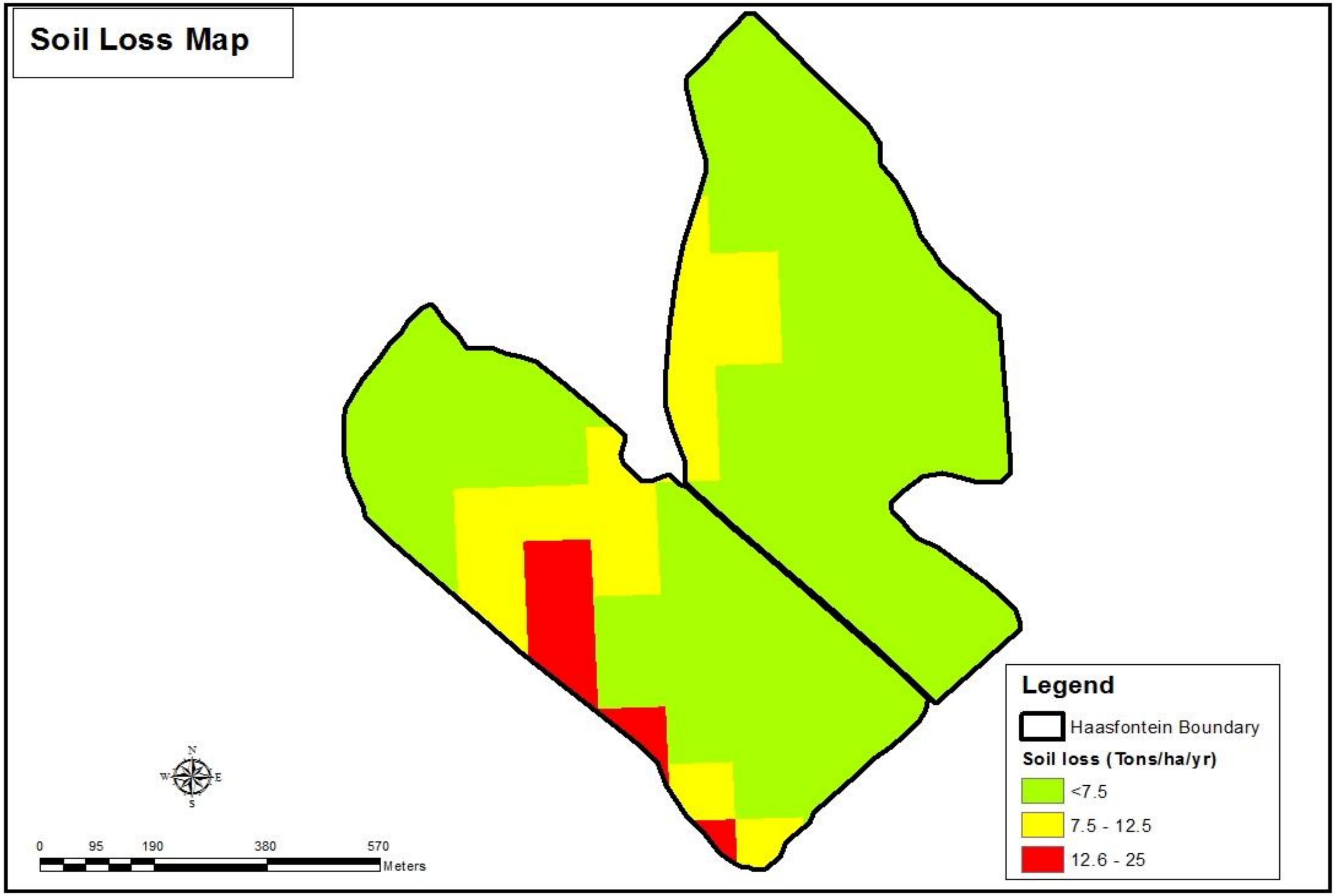

Fig. 4.3 Soil loss map

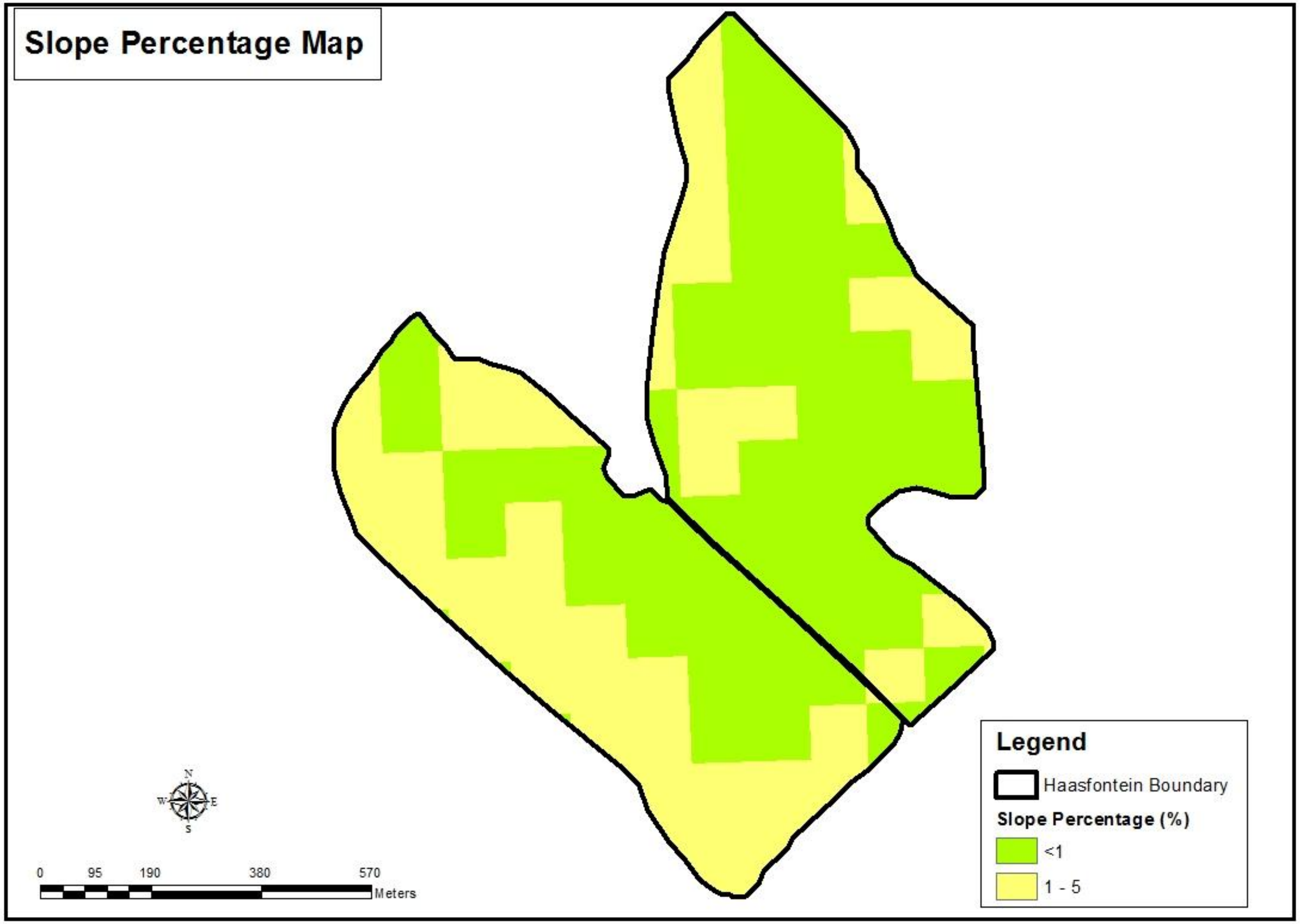

Fig. 4.4 Slope percentage map

According to Wortmann *et al.* (2005), erosion is the primary contributor to P runoff on many agricultural fields, particularly tilled fields. Most of the P runoff associated with erosion in most agricultural sites is attached to sediments (Sharpley and Smith, 1989). Furthermore, a study conducted by Eghball and Gilley (2001) reported that particulate P, sediment bound P, is the predominant form of P exported from agricultural lands. From these reports it can be expected that areas in the study site with high potential soil loss are expected to contribute more P into receiving water bodies when compared with areas with low potential soil erosion values.

For this study site, management practices that help reduce soil erosion can significantly reduce the amount of P transported into surface water bodies, because soil erosion determines the amount of particulate P movement in agricultural fields (USDA NRCS, 1998). Erosion control practices that can be directed toward on-site prevention include measures such as terracing, contour tillage, buffer strips, riparian zones, and cover crops (Tarkalson and Mikkelsen, 2004). A case study by Sharpley and Sheffield (2011) reported that a field with an erosion rate of 7.4 tons/ha/yr that made use of cover crops resulted in 70 to 85% reduction in total P lost.

4.4 Phosphorus application method and application rate

The method and rate of P application affects the magnitude of P runoff from agricultural fields (Kleinman *et al.*, 2002). Fig. 4.5 below shows that P application rate varied across the study site. The application rate map illustrates two classes of phosphate application rates, 0-14 and 15-30 P_2O_5 kg/ha/yr. Highest application rates of fertilizer P were located in the western portion of the study site. Based on the risk ratings given by Sharkoff *et al.* (2008), the western portion of the field had a relatively higher risk of P runoff compared to field portions that received lower P application rates.

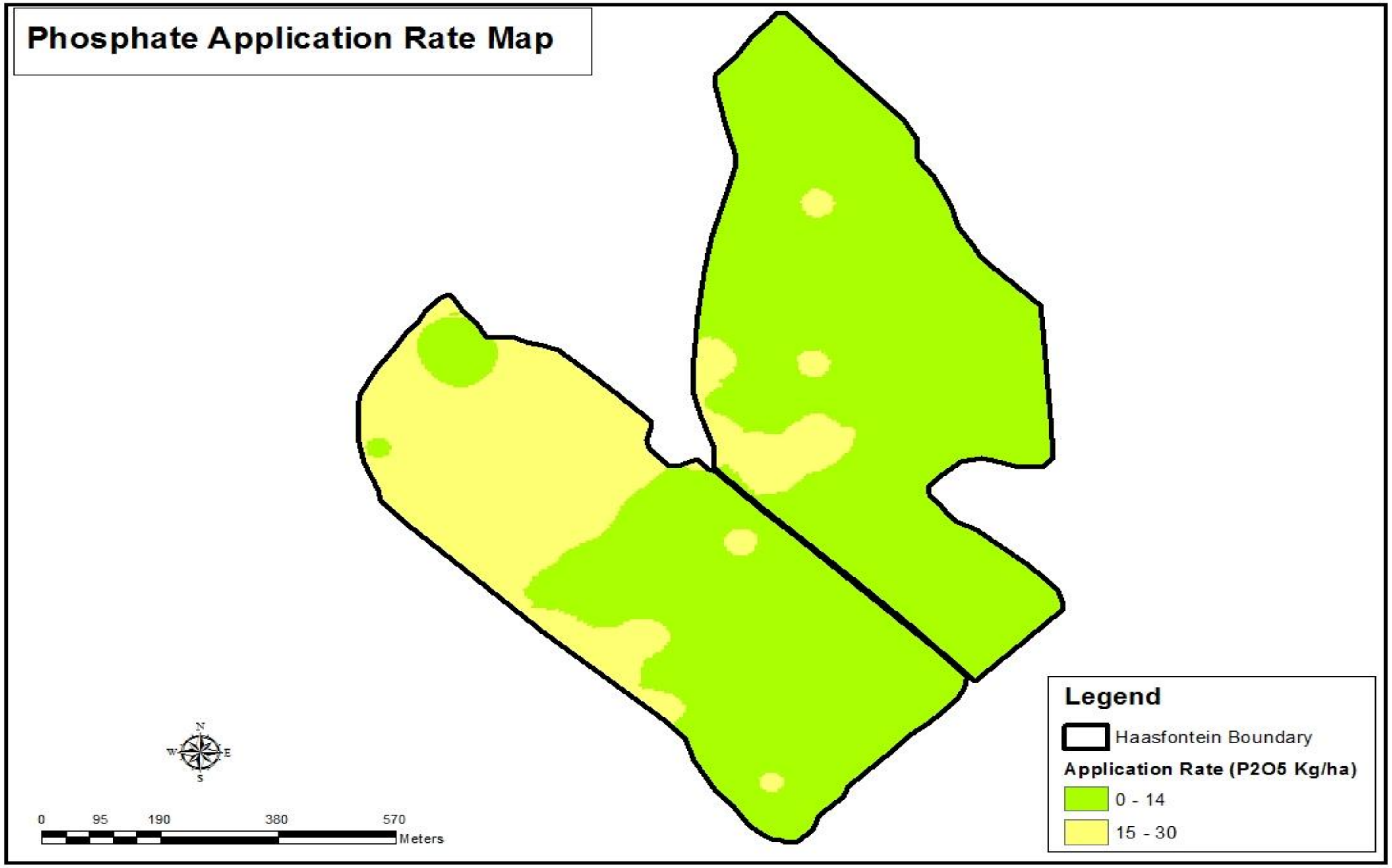

Fig. 4.5 Phosphate application rate map

In this study site, P fertilizer was applied in spring and incorporated within two weeks. A study conducted by Kleinman *et al.* (2004) indicated that fertilizer incorporation decreases P runoff compared to surface application by decreasing the concentration of P at the soil surface. However, it is important to note that incorporation can lead to soil disturbance. Excessive soil disturbance, under certain circumstances, can increase soil erosion, and can have a negative impact on soil and water quality (Tarkalson, 2001). Therefore, erosion control best management practices should be implemented. While incorporation of fertilizers lowers the risk P loss (Sharkoff *et al.*, 2008), over the long term, high application rates, regardless of application method, will increase P loss risk by increasing soil test P.

4.5 Phosphorus runoff risk

The phosphorus runoff risk map illustrates variation in the vulnerability of the study site to P runoff (Fig. 4.6).

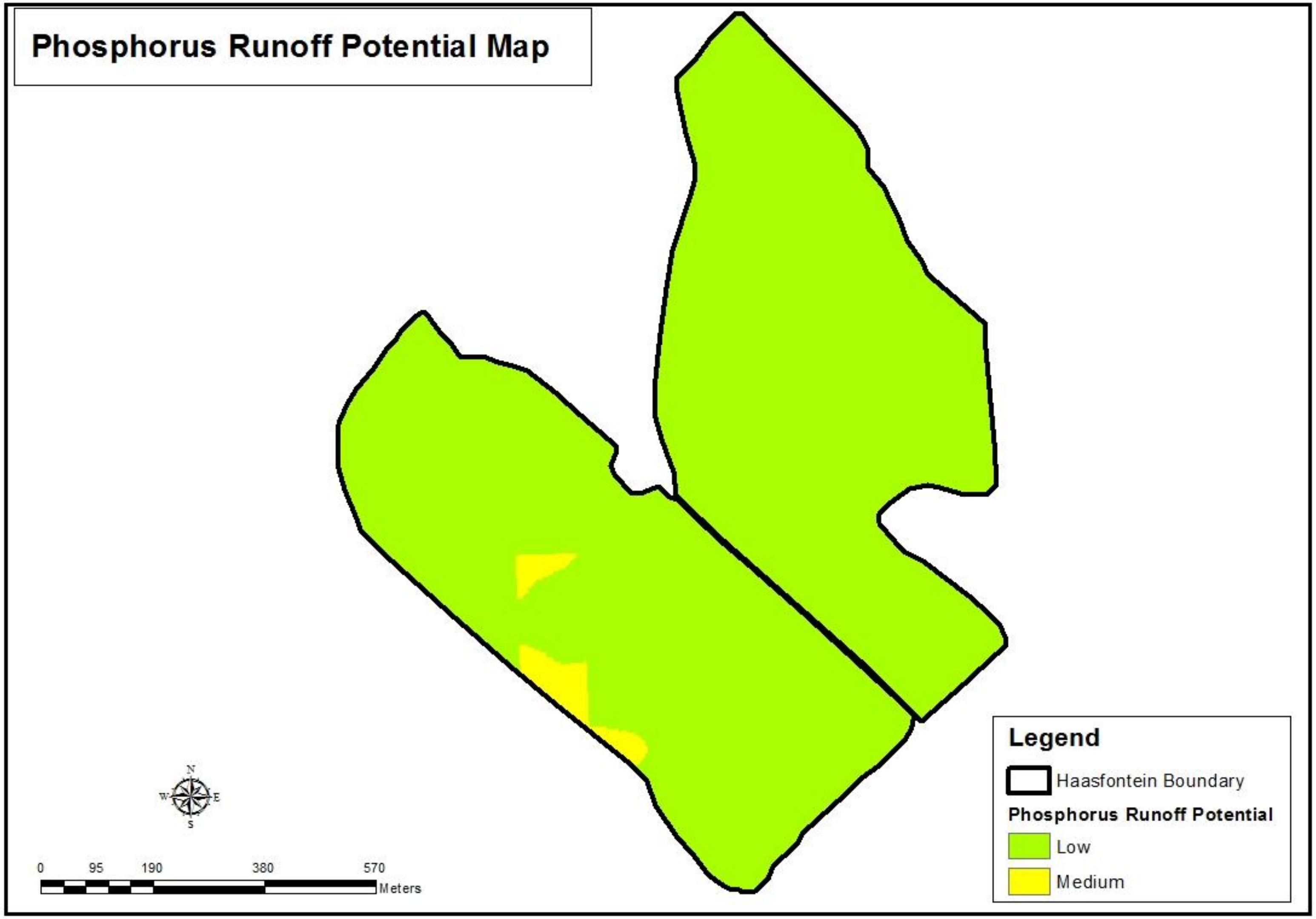

Fig. 4.6 Phosphorus runoff potential map

A large portion (73 ha) of the study site had low P runoff ratings. According to the P risk interpretation by Sharkoff *et al.* (2008), the low risk rating shows that a large portion of the field has a low potential for P off-site movement when managed at the current level. The P runoff risk map does however illustrate that there are portions of the study site (almost 2 ha) that have a medium P runoff risk and based on the recommendation given by Sharkoff *et al.* (2008), management changes should be considered to decrease risk of P runoff. Differences in site vulnerability to P runoff may be attributed to variation in site-specific conditions and management differences (soil loss potential, soil test P and P fertilizer application rates) that influence the likelihood of P runoff. Caution needs to be taken when managing the farm portions that have a medium risk of P runoff because changes in management practices e.g. increase of P application rate and method and soil test P may increase the medium rating to high risk P runoff rating. Yet, implementation of best management practices can decrease the medium rating to a low P runoff risk (Sharkoff *et al.*, 2008).

Variation in the potential of P runoff across the study site implies that there may be an advantage to the application of the P runoff risk assessment tool within a GIS framework. Geographic Information System can facilitate the identification of vulnerable areas within a field more precisely than conventional methods that rely on average measurements of site characteristics. In this study, if variations within site characterists (soil loss potential, soil test P and P fertilizer application rates) were not considered but the conventional methods were used, e.g. soil fertility estimation techniques that rely on averages, sites that have a medium risk of P runoff were not going to be identified. Conventional methods would have used average values of site characteristics ignoring the spatial variations that exist within the farm and consequently, areas that can potentially progress from medium risk to high risk ratings would not be prioritized for appropriate nutrient and soil management practices. Site variations need to be considered when site vulnerability to P runoff is assessed. As site vulnerability increases from low to very high, conservation practices and a long-term P management system needs to be implemented to reduce or eliminate P loss in runoff.

Areas with higher P runoff risk coincided with areas where STP was as low as 7 mg/kg. On the contrary, areas with low P runoff risk coincided with areas where STP was higher. This was an unexpected observation as many studies have shown P runoff potential to increase in sites where both STP and soil loss values are high (Sharpley *et al.*, 2003). The risk of P runoff from soils with low STP may be attributed high soil loss (Sharkoff *et al.*, 2008). This trend also indicates that even low P testing soils, as this is generally the case in South African soils can have a high risk of P runoff (Mandirigana *et al.*, 2005). For this reason, assessment of the risk of P runoff from agricultural sites in South Africa cannot be overlooked. Sites need to be assessed for the risk P runoff and mitigation strategies need to be employed to manage the risk.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Phosphorus runoff from agricultural fields and the subsequent loading to water bodies contributes to the eutrophication of surface water bodies. For this reason the study set out to assess the risk of P runoff at Vierfontein farm using the P environmental risk assessment tool. This tool was applied within a GIS framework in order to more precisely identify high risk areas within the study site. To achieve this aim, soil test P distribution, soil loss potential, and phosphate application method and rate were evaluated across the study site.

The main research findings of the study indicated that:

- The field had a large variation of soil test P. This variation could be attributed to differences in site specific conditions and management practices. Although Bray 1 P variation was not statistically different at $P \leq 0.05$, variation had agronomic and environmental implications.
- Soil loss potential varied within the field. Differences in soil loss potential could be attributed to topographic variation within the field. In addition, variation in soil loss potential affected the risk of P runoff. Sites with high soil loss potential had an increased risk of P runoff.
- The study site generally had a low risk of P runoff. However, there was a small portion that had a medium risk of P runoff. Areas with higher risk of P runoff coincided with areas of high soil loss potential.
- Areas of concern for P runoff vary spatially. GIS can facilitate in identifying areas with high P runoff risk.

- Low P testing sites can have a high risk of P runoff if they coincide with areas that have a high soil loss potential. These sites may contribute less P into receiving water bodies because of low P status. For this reason, management practices that reduce P runoff cannot be overlooked in areas with low P fertility status.

5.2 Recommendations

- It is recommended that erosion control practises be implemented in sites where there is a higher risk of P runoff. Strategies that can be used to reduce erosion include terracing, contour tillage, buffer strips, riparian zones, and cover crops.
- It is recommended that further research be done to correlate P runoff risk with actual losses of P from agricultural fields in a South African context

5.3 Limitations

- Study was done in a small scale hence variations in vulnerability of site to P runoff could not be fully demonstrated.
- Soil loss map was created at a very large scale hence soil loss potential at the study site may have been underestimated

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