

The use of geophysical methods to assess and compare soil moisture content under irrigation conditions

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DISCLAIMER

The author declares that all work contained in this dissertation is original work and research, and the appropriate citations, references and acknowledgements have been made to the authors, organisations and companies' work or publications that were used in this study. The author also declares that the research and findings of this dissertation have not been previously, in its entirety or in part, submitted to any other university or institution. This study was conducted at the Centre for Water Sciences and Management, Department of Natural and Agricultural Sciences, North-West University. The study was done under the supervision of Mr J. Koch and Mr P.W. van Deventer, together with Omnia and THRIP.

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ABSTRACT

Drought and water scarcity are common and recurring phenomena in South Africa, and for this reason water management (and more specifically the management of soil moisture content) plays a pivotal role in the success of agricultural activities. The aims of this study was, firstly to compare datasets between the different geophysical methods used (electromagnetic, neutron scattering and frequency domain reflectometry). Secondly, this study aimed at locating and discussing areas of concern located on the pivot under investigation, and lastly, to assess the cost- and labour efficiency between the methods used. In this study two CMD Electromagnetic Conductivity Meters (collectively referred to as CMD, or individually referred to as the CMD Mini-Explorer and CMD Explorer), the CPN 501DR Depthprobe (Neutron probe) and the Diviner 2000 (Diviner) were used to determine the statistical probability of yielding similar and reliable results. Both statistical (T-test and ANOVA analyses) and visual comparisons were made to determine the reliability of each method, as well as to established the most cost- and labour effective method of geophysical analysis of soil moisture content. Gravimetric and volumetric soil moisture content samples were taken and analysed to compare with the three different geophysical methods. During this study, three areas were identified as problematic, which could lead to lower quality and quantity crop production in the specific study area. Furthermore, it was found that the comparison of the volumetric-, Neutron probe- and Diviner datasets had high statistical probabilities of having similar and reliable results, should they have been used separately for measuring SMC. When the CMD datasets were included in the statistical analyses, the results suggested that the CMD would not have similar and reliable results compared to the other methods. This was attributed to the different outputs (volumetric water content as compared to electrical conductivity) given by the different apparatuses. The visual comparisons, on the other hand, showed that there were positive spatial trends between the different methods used. Suggesting that the CMD could indeed be used to produce a reliable indication of SMC measurements (if the proper environmental factors and variables are considered). This study concluded that, when considering a geophysical method for large-scale and long-term use, the CMD is by far the most appropriate method for indicating soil moisture content (considering the high resolution and the labour efficiency of the apparatus). When a geophysical apparatus and method is being considered for small-scale, continuous and long-term soil moisture content monitoring, the Diviner 2000 was the apparatus of choice looking at cost- and labour efficiency.

KEYWORDS: Electromagnetic, frequency domain reflectometry, geophysical analysis, neutron scattering, soil moisture content.

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LIST OF SYMBOLS AND ABBREVIATIONS

$^{\circ}\text{C}$	Degrees Celsius – A measurement of temperature.
α	Alpha – Which in the case of this study, was set at 0.05. Alpha is a value used in both the T-test- and the ANOVA analyses.
μ_1	Dataset one – A symbol used to represent a dataset in the T-test- and ANOVA analyses.
μ_2	Dataset two – A symbol used to represent a dataset in the T-test- and ANOVA analyses.
ρ_s	Density of a solid (also called the ' <i>mean particle density</i> ' in other literature).
ρ_b	Dry bulk density – An expression of the ratio between the mass of solids to the total volume of the soil.
π	Pi – A constant in the calculation of volume for a cylinder.
θ	Volumetric water content (also called ' <i>volumetric wetness</i> ' in other literature) – This is a measurement of 'volumetric' water content, most often as a percentage value, in the total volume of soil.
ATV	All-terrain vehicle – A four wheeled motorised vehicle.
ANOVA	Analysis of variance – A statistical analysis method used in this study to determine statistical probabilities between three or more datasets at a time.
$\text{cm}\cdot\text{cm}^{-3}$	Centimetre per cubic centimetre – A measurement of volumetric water content.
CMD	CMD Electromagnetic Conductivity Meters – An electromagnetic method used for the geophysical investigation of soil moisture content.
<i>df</i>	Degrees of freedom – A term used to give the amount of values, used in the statistical analysis (i.e. T-test and ANOVA), that has the freedom to vary.
Diviner	Diviner 2000 – A frequency domain reflectometry method and apparatus used in this study to measure soil moisture content.

EC	Electrical conductivity – A measurement of soil salinity, usually expressed in milliSiemens per metre.
EM	Electromagnetic – A geophysical method that generates an electromagnetic field in the subsurface, and measures the ability of the subsurface to conduct electricity (also referred to as conductivity).
F-crit	F-critical – Used in ANOVA analyses to determine (alongside the p-value) whether the results found were indeed significant or not.
F-stat	F-statistic (also referred to as f value) – Used in ANOVA analyses to determine whether the means of two (or more) datasets differ significantly.
Fa	Air measurement – Used in the field calibration process of the Diviner 2000.
Fs	Resonant frequency measurement of soil – A measurement taken by the Diviner 2000.
Fw	Water measurement – Used in the field calibration process of the Diviner 2000.
FEM	Frequency domain electromagnetic method – A type of geophysical investigation, working in the frequency domain.
FDR	Frequency domain reflectometry – A geophysical method to measure soil moisture content indirectly.
GHz	Gigahertz – Unit of measurement for electromagnetic frequencies, where one GHz is equal to that of one billion (1 000 000 000) hertz.
GPS	Global positioning system – A system used to determine geographical coordinates (latitude and longitude) of an attribute/real world feature.
h	Height – Used to calculate the volume of a cylinder.
H₀	Null hypothesis – Used in T-test analyses and ANOVA analyses, where H ₀ suggests that the datasets analysed have a high probability of resulting in similar/identical results.
H₁	Alternative hypothesis – Used in T-test analyses and ANOVA analyses, where H ₁ suggests that the datasets analysed do not have a statistical probability of resulting in similar/identical results.

Hp	Primary magnetic field – Generated by an alternating current that passes through the transmitter coil.
Hs	Secondary magnetic field – If a conductive material is encountered, it produces secondary magnetic fields that is measured by the receiver coil.
Hz	Hertz – Unit of measurement for electromagnetic frequencies.
HCP	Horizontal coplanar orientation of the transmitter- and receiver coils – A term used when working with the CMD and other electromagnetic apparatuses.
HMD	Horizontal magnetic dipole – A term used when working with the CMD and other electromagnetic apparatuses. A vertical coil orientation results in a horizontal magnetic dipole.
HLEM	Horizontal loop electromagnetic – Orientation of the transmitter- and receiver coils.
K	Hydraulic conductivity – A measurement of the capacity of a certain material to transmit water.
KHz	Kilohertz – Unit of measurement for electromagnetic frequencies, where one KHz is equal to that of one thousand (1 000) hertz.
m²	Square metre – A measurement of area.
mm	Millimetre – A unit of volume used for liquids and gasses. Also a unit used for the measurement of distance.
mS/m	milliSiemens per metre – A unit of measurement for electrical conductivity.
Ms	Mass of a solid – Used in the calculations of gravimetric water content, where Ms is the mass of the dry solid/sample.
Mw	Mass of water – Used in the calculations of gravimetric water content, where Mw is the mass of water lost by the sample during the process of oven drying.
p-value	A value between one and zero, used in both T-test- and ANOVA analyses.
ppm	Parts per million.
P	Count Ratio – A term used for the readings taken by the Neutron probe.
PVC	Polyvinyl chloride tubes – The access tubes used in this study.

r^2	Square radius – Used to calculate the volume of a cylinder.
R^2	Regression coefficient – Used in the calibration of the different apparatuses (volumetric, Neutron probe and the Diviner 2000) used in this study.
Rx	Receiver coil – A term used when working with the CMD and other geophysical methods. Rx refers to the coil receiving signals.
SF	Scaled frequency – Measurements taken by the Diviner 2000, where the air measurements, resonant frequency measurement of the soil and the water measurements are used to calculate the scaled frequency.
SS	Sum of squares – A term used in the T-test and ANOVA analyses of this study.
SMC	Soil moisture content – A term used for the amount of moisture that is present in a soil.
Tx	Transmitter coil – A term used when working with the CMD and other geophysical methods. Tx refers to the coil transmitting signals.
T-crit	T-critical – Used in T-test analyses to determine (alongside the p-value) whether the results found were indeed significant or not.
T-test	A statistical analysis method used in this study to determine statistical probability between two datasets at a time.
TEM	Time domain electromagnetic method – A type of geophysical investigation, working in the time domain.
USB	Universal serial bus – A device used to transfer data/information between two computerised apparatuses.
V	Volume – In the case of this study, V was used to symbolise volume.
V_t	Volume of the soil sample – In this case, V _t was used to symbolise the total volume of the sample used.
V_w	Gravimetric water content – In the case of this study, V _w was used to symbolise gravimetric water content.
VCP	Vertical coplanar orientation of the transmitter- and receiver coils – A term used when working with the CMD and other electromagnetic apparatuses.

VLF	Very low frequency – A term used to describe geophysical methods operating at 15 - 30 KHz.
VMD	Vertical magnetic dipole – A term used when working with the CMD and other electromagnetic apparatuses. A horizontal coil orientation results in a vertical magnetic dipole.
VLEM	Vertical loop electromagnetic – Orientation of the transmitter- and receiver coils.

GLOSSARY

A

Access tubes Tubes or pipes that are inserted into the soil to allow for the apparatuses' probes to be lowered into the soil.

Analysis software Computer software used for analysing and processing data collected in the field.

ArcGIS This is a geographic information system (GIS) that is used to store, capture, analyse, organise and visually represent data in an appropriate manner as to accurately present all necessary data.

Georeferenced image An image (i.e. satellite image of an area) that has been referenced to a geographic coordinate system (GCS) with the use of known GPS coordinates and other real-world objects and features.

Shapefile A nontopological format that makes it possible to store attribute data and geomorphic location of geographical features.

Symbology A system used to represent different data in different ways, shapes, colours, colour schemes and sizes.

WGS 1984 Geographic coordinate system that makes it possible to calculate coordinates on the surface of the earth.

Microsoft Excel Software for statistical and mathematical analysis of data, with various graphing tools.

Linear trend line This is a best-fitting straight line through a dataset (i.e. that is plotted on a scatterplot graph). This straight line can be used to determine whether data have positive or negative trends. This can also be used to determine R^2 and calibration equations, as done in this study.

Polynomial trend line This is a best fitting curved line through a dataset, and could also be used to determine R^2 and calibration equations.

Surfer 11 A software package developed for *Microsoft Windows*. This software package makes it possible to generate contour maps, base maps, shaded relief maps, watershed maps, image maps, 3-Dimensional surface maps, 3- Dimensional wireframe maps and vector maps. This software can also be used to construct profiles, as well as to determine length, distance, area and volume.

Kriging This is an interpolation method that uses trends in the map, and data, to extrapolate values for areas where no data is available. This method was used in this study to interpolate the maps used at different depths, with the volumetric-, Neutron probe-, Diviner- and CMD datasets.

Anomaly An abnormality or irregularity (whether it is positive or negative) in a dataset or on a map, which could be an indication of a change in circumstance, e.g. in the case of this study, an area with higher or lower amounts of soil moisture content.

Apparent conductivity Measurements showing secondary magnetic fields, hence referred to as apparent conductivity. Apparent conductivity is the inverse of apparent resistivity, and is measured in milliSiemens/metre or Siemens/metre.

Atmospheric interference A term used to describe why measurements for the Neutron probe could vary or be inaccurate. This term suggests the neutrons that are scattered into the environment, either escaping into the atmosphere or does not completely interact with the soil. This then causes some of the neutrons to be lost, and is not received and measured by the receiver, which in turn could lead to inaccurate or unexpected results.

Auger drill A hand drill used to take gravimetric and volumetric samples, as well as being used to drill holes for the installation of access tubes.

C

Clay content A term used to describe the amount (or percentage) of clay present in a soil or area under investigation. Sand, silt and clay contents are usually interpreted together.

Coil orientation A term used to describe the orientation (vertical or horizontal) of the transmitter- and receiver coils, in this case referring to the CMD.

Control unit A unit used to operate an apparatus, store data and for operational settings.

Count Ratio This is a term used for the readings that is taken by the Neutron probe.

D

Density This is the mass of a solid, per unit volume of the solid. Density is often expressed as grams/cubic centimetre ($\text{g}\cdot\text{cm}^{-3}$) or metric tons/cubic metre ($\text{Mg}\cdot\text{m}^{-3}$).

Absolute density A term used in this study to describe the density measurements after calibration of the relative density measurements.

Bulk density This is the ratio between the mass of dry soil to the total volume of soil (the total volume including the solid particles and the pore spaces).

Relative density A term used in this study to describe the density measurements taken in the field, prior to the calibration of absolute density.

Drought The lack of precipitation over a period of time.

Agricultural drought A drought usually occurring between three and six months, and typically occurs during the planting season. This could lead to damage of crops or decrease the quantity and quality of crop yields.

Hydrological drought A drought that typically occurs for one to two (or more) years. A hydrological drought has definite effects on the subsurface and surface supply of water.

E

Electrical conductivity The capacity of a soil (or other material) to transmit or conduct an electrical current. Electrical conductivity in soils, water or dissolved solutions can be expressed as deciSiemens/metre (dS/m), milliSiemens/metre (mS/m) or Siemens/metre (S/m).

F

Fertiliser An organic or inorganic substance or material (whether natural or synthetic) that is added to soil, to provide certain essential elements necessary for growth of plants.

G

Gantt chart A chart used to illustrate a schedule of a project, which includes time management, deadlines, milestones, tasks, possible problems that could be encountered and to show the overall progress of a project/study. The Gantt chart is a good way of keeping up to date with the project and the progress thereof, especially if the chart is kept up to date as time passes.

Geophysics A science that uses physics and other physical properties, to investigate the Earth and other planets. A key concept of geophysics is the collection of measurements and data on physical properties, and very importantly, the distribution thereof. A large part of geophysics is finding anomalies, and knowing what these anomalies mean. Geophysics is a broad term used to describe the study of the interior of Earth, whether it is for a couple of metres to hundreds of kilometres.

Agricultural geophysics Also referred to as '*Agro-geophysics*', and is a branch (or sub-discipline) of applied geophysics. This sub-discipline is the use of geophysical methods and apparatuses in soil science and agriculture, where this sub-discipline is often used in conjunction with bio-geophysics.

Applied geophysics A term used for geophysical studies mainly in the fields of geology, soil sciences, environmental sciences, hydrology

and geohydrology. The term 'applied geophysics' generally implies that the studies conducted, are at depths of 100 metres or less.

Archaeo-geophysics The use of geophysics in the field of archaeology, to aid in the finding of fossils and other pre-historic findings such as buried cavities used in ancient times for shelter. This sub-discipline of geophysics is often used in conjunction with engineering and construction.

Bio-geophysics A sub-discipline of geophysics that makes use of microorganisms and their activities in soils and geological units. This is often used in conjunction with agro- and forensic geophysics.

Environmental geophysics A term used to describe geophysical investigations for environmental purposes. This can include a variety of different aspects, for example the mapping of variations found in pore fluid, salinity, underground water flow, as well as the impact- and the spread of pollution in the subsurface. In environmental geophysics, physical effects and chemical effects can play equally important roles.

Engineering geophysics This sub-discipline of geophysics mainly concentrates on structures and the impact/influence of different types of materials for different purposes, i.e. construction of buildings.

Exploration geophysics Shortly put, it is the utilisation of geophysical methods and techniques to find economically valuable commodities (e.g. deposits of metalliferous minerals and ore deposits, fossil fuels – such as coal, oil and gas – bulk mineral and gem deposits, and ground water).

Forensic geophysics Geophysical methods that is used to conduct investigations that could be used as evidence in a court of law.

- Glacio-geophysics** The use of geophysical methods and techniques in glaciology, which largely overlaps with hydro-geophysics.
- Hydro-geophysics** Geophysical methods and techniques used for the exploration and study of ground water. This sub-discipline of geophysics is largely used in conjunction with exploration- and environmental geophysics.
- Geophysical investigation** A term used in this study that refers to the use of one or more geophysical method or apparatus to investigate the subsurface.
- Active method** Active methods make use of signals that are produced artificially and then transmitted (by the transmitters) into the subsurface. These artificially generated signals then interact with the surrounding materials, and the altered signals are then picked up (by the receivers) and can then be processed, displayed and interpreted.
- Invasive method** A method that requires the disturbance of the soil and subsurface.
- Non-invasive method** A method that does not require the disturbance of the soil or the subsurface.
- Passive method** These are methods that utilises natural signals, or fields, that are generated by, and associated with, the Earth.
- Geophysical methods and apparatuses** Three geophysical methods, and four apparatuses, were used in this study. The methods (and apparatuses) include electromagnetic (CMD Mini-Explorer and CMD Explorer), frequency domain reflectometry (Diviner 2000) and neutron scattering (CPN 501DR Depthprobe).
- CMD** CMD Electromagnetic Conductivity Meters – a product range by GF Instruments. In the text, this apparatus is collectively referred to as the CMD, or individually referred to as the CMD Mini-Explorer and CMD Explorer. This is a non-invasive electromagnetic geophysical method, which is most

commonly used for geological and other environmental studies. This apparatus is often used in investigations for the detection of geological units and underground pipes, as well as to determine the excavatability of the subsurface.

Eddy current When a primary magnetic field (H_p) passes through the soil and comes in contact with a conductive material, it undergoes a phase shift and then generates eddy currents.

Slingram This is a system that has a pair of transmitter- and receiver coils with a set distance from each other. A primary field is generated by the transmitter coil and induces an electrical current in the soil. These currents then produce secondary magnetic fields (H_s), which is then measured as either in-phase and/or quadrature. These measurements are then used to make interpretations of the subsurface.

Diviner 2000 This is a geophysical method that uses frequency domain reflectometry, for the indirect measurement of soil moisture content. This is an active and invasive method, which measures the soils' dielectric constant, as the soil acts as a capacitor between the two electrical plates. Soil moisture content is measured by the Diviner 2000 by measuring the capacitance to determine the dielectric constant. Thus, these apparatuses are commonly referred to as capacitance probes.

Air count A reading taken by the Diviner 2000 to calibrate for field measurements. This reading is used to determine a baseline for a 'dry' reading.

Capacitance This is a term used to describe the potential of the soil (or other materials) to store an electric charge, or to describe the change in ratio between the electric charge and change in electric potential.

Capacitance probe A term often used instead of frequency domain reflectometry probe/device.

Capacitor A device or apparatus that consists of one (or more) pair(s) of conductors, which is separated by an insulator, and is used to store an electric charge.

Dielectric constant The ratio of capacitance formed by the capacitor with air between the two plates (dielectric) and with a medium (such as soil) between the two plates.

Probe The probe referred to when discussing the Diviner 2000, is the rod that is lowered into the soil that measures the depth and soil moisture content.

Water count A reading taken by the Diviner 2000 to calibrate for field measurements. This reading is used to determine a baseline for a 'wet' reading, which is used as an indication when the probe comes in to direct contact with water.

Neutron probe CPN 501DR Depthprobe. This is a nuclear technique that is described as a neutron scattering method. This method measures soil moisture content indirectly, through neutron thermalisation. The density of the thermalised cloud of neutrons is a function of the soil moisture content present in the vapour-, liquid- or solid phase. The amount of thermalized neutrons that returns to the detector per unit of time over a known soil volume (or known volume of influence) are then counted, where the soil moisture content can then be determined.

Gamma radiation A result of a radioactive nuclei that emits high energy photons.

Neutron thermalisation This is when fast moving neutrons with a high amount of energy (from the radioactive source in the probe) are thermalised, or slowed, when coming into contact with the soil due to elastic collisions with hydrogen nuclei in H₂O and other minerals. The receiver or detector then counts these thermalized neutrons that returns to the probe. The average amount of energy lost due to these collisions are much larger when these

neutrons collide with lighter elements as compared to colliding with heavier elements. The result being that, in soil, hydrogen slows down fast moving neutrons a lot more effectively than other elements present.

Probe The probe referred to when discussing the Neutron probe, is the casing lowered into the access tubes that measures SMC or soil density.

Gravimetric water content The mass of the water contained in a 'wet' soil sample, relative to the mass of a 'dry' soil sample.

Grid system A term used in this study to describe a grid (consisting of latitudinal and longitudinal lines) that was used to determine specific GPS coordinates, where measurements and samples needed to be taken, as well as the coordinates where holes were drilled to install access tubes. These grids were also used as a guideline for taking measurements with the CMD Mini-Explorer and CMD Explorer. The size of the grid system used was dependant on the apparatus it was designed for.

H

Hydraulic conductivity A measurement of the capacity, of a certain material, to transmit water. Hydraulic conductivity can be defined as being directly proportionate to the hydraulic gradient (Darcy's law) and inversely proportionate to the specific discharge. Hydraulic conductivity can be measured in metres per second (m/s) or metres per day (m/d).

L

Lateral flow of water A term used in this study that refers to the underground movement (or flow) of water, which is parallel to the slope of the area, under gravitational forces.

M

MilliSiemens per metre A unit of measurement for electrical conductivity.

P

Palaeochannel A term used to describe a remnant stream channel or an inactive river that has been buried by-, or filled with younger sediment.

Pivot irrigation system A term used for an irrigation system where sprinklers rotate around a centre pivot.

Precision farming A management system where close observations, measurements and responses are made for the effective management of crops.

Profile In this study, the term profile(s) refers to the hole(s) drilled where the access tubes were installed. These profiles were then numbered, and the coordinates of all the holes drilled were noted.

R

Regional climate The assessment of climatic conditions (i.e. precipitation and temperature) over a long period of time.

Resolution A term used to describe the detail and/or accuracy of a visual display of data.

Restrictive layer Used in this study to describe an impenetrable layer of rock or hard sediment in the subsurface. In soil science this is referred to as a hard plinthic B horizon, which is defined by the accumulation of manganese- and iron oxides that cannot be cut or easily broken by a spade.

S

Soil acidity A term referring to the pH of a soil, which is expressed with a pH value of less than seven.

Soil core sampler A cylindrical apparatus, with a known volume, that is used to measure the density of a soil sample.

Soil form A soil form is defined as a classification for soils with similar physical and/or chemical characteristics, resulting in the possibility of separating the soil profile into recognisable horizons as definite and discrete entities.

Avalon Orthic A-horizon, on a yellow-brown apedal B-horizon, on a soft plinthic B-horizon.

Constantia Orthic A-horizon, on an E-horizon on a yellow-brown apedal B-horizon.

Hutton Orthic A-horizon on a red apedal B-horizon.

Longlands Orthic A-horizon on an E-horizon on a soft plinthic B-horizon.

Wasbank Orthic A-horizon on an E-horizon on a hard plinthic B-horizon.

Westleigh Orthic A-horizon on a soft plinthic B-horizon.

Soil moisture content Soil moisture content (also referred to as 'soil moisture' or 'soil water content' in other literature) generally refers to the water in the soil (present as liquid and/or vapour) and the amount thereof. When SMC is measured or described, it is generally applicable to the upper layer of the soil under investigation – the layer(s) interacting with the atmosphere. SMC is most commonly expressed as volumetric soil moisture.

Soil salinity A term used that refers to the amount of soluble salts that is present in a soil.

Soil structure A term used to describe the arrangement (or combination) of primary soil particles in secondary particles, peds or units.

Soil texture A term used to describe the ratio of sand, silt and clay percentages in a soil.

Statistical data analysis

ANOVA A statistical analysis method used in this study to determine statistical probability between three or more datasets at a time.

H₀ A symbol used to represent the 'null hypothesis' in T-test analyses and ANOVA analyses, where H₀ suggests that the datasets analysed have a high probability of resulting in similar/identical results. The null hypothesis was defined as H₀: $\mu_1 = \mu_2$.

H₁ A symbol used to represent the ‘alternative hypothesis’ in this study for T-test analyses and ANOVA analyses, where H₁ suggests that the datasets analysed have little to no probability of resulting in similar/identical results. The alternative hypothesis was defined as H₁: $\mu_1 \neq \mu_2$.

T-test A statistical analysis method used in this study to determine statistical probability between two datasets at a time.

T

Topography A term used to describe the shape and features of the surface of the Earth, which could refer to landforms, landscapes and height above sea-level.

V

Volumetric water content Volumetric water content (also called ‘*volumetric wetness*’ in other literature) is a measurement of the volumetric amount of water, most often expressed as a percentage value, in the total volume of soil.

CHAPTER 1: CONCEPTUALISATION OF THE PROJECT

1.1 BACKGROUND

Water scarcity is on the rise and is rapidly becoming an international problem (Meigh *et al.*, 1999; Van Loon, 2015). The causes of water scarcity are mainly due to the large continuous increase in population, urbanisation and the continued improvement of living standards (Meigh *et al.*, 1999). This greatly increases the pressure on water supplies, due to the increasing demand for food production and industrial activities (Meigh *et al.*, 1999). Meigh *et al.* (1999) and Van Loon (2015) claims that anthropogenic influences and activities such as climate change (due to the increase of atmospheric greenhouse gasses) and deforestation could worsen the above-mentioned problems in the near future. In South Africa, drought (the lack of precipitation over a period of time) is seen as a common and recurring phenomena (Rouault & Richard, 2003). Rouault and Richard (2003) states that the impact a drought has on society, mainly consists of the duration and intensity thereof. Such severe climatic events can have an enormous effect on crop production and livestock, and occurs in agricultural regions worldwide (Rosenzweig *et al.*, 2001). According to Rouault and Richard (2003), over the last five decades, South Africa has been characterised by large variabilities in interannual rainfall.

The timescale of a drought determines whether it is classified as an agricultural- or hydrological drought. An agricultural drought (usually between three to six months) is typically during a planting season when the lack of precipitation could lead to crop failure and a decrease in crop yield (Boken *et al.*, 2005; Keyantash & Dracup, 2002; Rouault & Richard, 2003; Wilhelmi & Wilhite, 2002). If the drought occurs for a longer period of time (one to two years or more) and has a definite effect on subsurface and surface supply of water, it is considered a hydrological drought (Rouault & Richard, 2003; Van Loon & Laaha, 2015; Van Loon & Van Lanen, 2012; Van Loon, 2015). Even though both an agricultural- and hydrological drought is due to the lack of precipitation over a period of time, a hydrologist is mainly concerned about the impact the drought has on the hydrological system (Marshall, 2013; Narasimhan, 2009; Rouault & Richard, 2003). Forming a small ($\pm 0.15\%$ of the total amount of fresh water), but important part of the hydrological system, is the soil moisture (Larson *et al.*, 2008; Marshall, 2013; Narasimhan, 2009; Robock, 2015; Western *et al.*, 2002). The soil moisture content (SMC) greatly influences plant growth and the transport of nutrients in soil (Fayer & Gee, 2005; Haberland *et al.*, 2015; Larson *et al.*, 2008; Molz, 1981; Robock, 2015). Therefore, agricultural activities such as crop production are much more dependent on the available soil moisture than most other natural variables (Fayer & Gee, 2005; Haberland *et al.*, 2015; Larson *et al.*, 2008; Molz, 1981; Robock, 2015). Subsequently, it is very important

to constantly measure SMC to ensure that the soils are irrigated properly so as to maximise crop yield (Fayer & Gee, 2005; Girona et al., 2002; Haberland et al., 2015). For the above-mentioned reason, it is important to consider different approaches to ensure that water is managed correctly in an agricultural setting.

This study aims at comparing geophysical techniques applicable to soil moisture estimation, to ensure that SMC is managed correctly and efficiently, thereby saving time, decreasing expenses (by minimising water- and electricity usage on pivots) and maximising crop yields. Furthermore, the study aims at locating and assessing problematic areas in the study area. Lastly, this study also aims at determining the best and most efficient method for soil moisture investigation, and therefore decreasing the time and cost of data collection for soil moisture. Thus, the question arises: Which geophysical technique is the least costly and time consuming, as to ensure the most accurate and reliable data for the measurement of soil moisture content in both large-scale and small-scale investigations?

1.2 INTRODUCTION

1.2.1 A brief introduction to the field of geophysics

Geophysics, in the most basic sense, is a science that uses physics and other physical properties to investigate the Earth, but is also used to investigate the Moon and other planets (Kearey *et al.*, 2013; Reynolds, 2011). Collecting measurements and data on the physical properties (and the distribution thereof), on or near the surface of the earth, can give quite an accurate and good representation of the interior of the earth - whether it is for a couple of metres or hundreds of metres (Kearey *et al.*, 2013). Although the term '*Geophysics*' can be used as a very broad term to describe a whole range of measurement for various uses (e.g. astronomy, global geophysics, forensic geophysics, glacio-geophysics and archaeo-geophysics), it is defined in a more restricted way to specifically be applicable to the Earth (Kearey *et al.*, 2013; Reynolds, 2011). Due to the aforementioned definition (also in a sense being a broad explanation), a variety of subdivisions - of the field known as '*Geophysics*' - have been established. Mainly in the field of geology, soil sciences and hydrology, the term '*Applied geophysics*' is used, and this generally implies that the studies conducted are at depths of 100 metres or less (Reynolds, 2011). According to Reynolds (2011), the field of applied geophysics includes studies about the Earth's crust, studies which are done for engineering purposes (e.g. surveys to delineate shallow sub-surface structures), groundwater exploration, mineralogical- and other economical resource exploration, the locating of buried cavities, historic- or current mineshafts and archaeological remnants, and finally studies where underground cables or pipes are mapped.

It is clear that the field of geophysics, and more specifically applied geophysics, is a large network of interconnecting disciplines with mainly three sub-disciplines, which is shown in Figure 1. The main difference between engineering geophysics and environmental geophysics, is the fact that engineering geophysics primarily concentrates on structures and the types of different materials (Reynolds, 2011). Where environmental geophysics can include a variety of different aspects, for example the mapping of variations found in pore fluid, leading to different conductivities that could then be used to detect pollution plumes found in subsurface water (Reynolds, 2011). In environmental geophysics, physical effects and chemical effects can play equally important roles, e.g. where the salinity of the soil under investigation can have an adverse effect on the electrical conductivity (EC), which is due to an increase of salinity leading to an increase in electrical conductivity (Corwin & Lesch, 2005; Reynolds, 2011; Rhoades *et al.*, 1989). A large advantage of certain geophysical methods, is that it makes it possible to do non-invasive investigations of the subsurface (through the use of remote sensing techniques, and thereby not disturbing subsurface materials), where this might prove critical in certain circumstances (Milsom & Eriksen, 2011; Reynolds, 2011). Examples of non-invasive methods include electromagnetic (EM) methods, radiometric methods and gravity methods. There are, on the other hand, some invasive, more direct methods of measurement. Two examples of invasive techniques are the gravimetric- and volumetric measurements of soil moisture.

Figure 1 is a schematic representation, adapted from Reynolds (2011), of the main disciplines and sub-disciplines in applied geophysics and how they overlap. With this, Reynolds (2011) explains that in the field of geophysics, certain surveys and investigations may have these disciplines and sub-disciplines overlapping. The main disciplines include engineering-, exploration- and environmental geophysics. Engineering geophysics, as mentioned, is mainly concerned with surveying the shallow sub-surface to identify possible structures and materials which could likely have engineering implications (Reynolds, 2011; Sheriff, 2002). Exploration geophysics, shortly put, is the utilisation of geophysical methods and techniques to find economically valuable commodities (e.g. deposits of metalliferous minerals and ore deposits, fossil fuels – such as coal, oil and gas, bulk mineral and gem deposits, and ground water) (Kearey *et al.*, 2013). Environmental geophysics can be described as the use of various geophysical techniques for investigating near surface physical-, chemical- and biological occurrences, all of which could have an influence on the immediate environment and the management thereof (this includes subsurface pollution, crop management, SMC management, and geological units and -structures such as dikes and sills) (Milsom, 2003; Reynolds, 2011).

According to Reynolds (2011), the six sub-disciplines of environmental geophysics, which are shown in Figure 1 to largely overlap within applied geophysics, are:

- i. Hydro-geophysics – a discipline overlapping with both exploration- and environmental geophysics, and is the use of geophysical techniques for the exploration and study of groundwater.
- ii. Glacio-geophysics – this is the application of geophysics in glaciology, which could largely overlap with hydro-geophysics.
- iii. Agro-geophysics – the use of geophysics in soil science and agriculture, where this discipline could also be used in conjunction with bio-geophysics.
- iv. Bio-geophysics – a discipline that makes use of geophysical evidence of microorganisms' activities in soil and other geological units. This discipline can be combined in studies with agro-geophysics and forensic geophysics.
- v. Forensic geophysics – in this discipline, geophysics is used to conduct investigations that could help with evidence, which could be used in a court of law.
- vi. Archaeo-geophysics – here geophysics is used in the field of archaeology, to aid in the finding of fossils and other pre-historic findings such as buried cavities used in ancient times for shelter. Archaeo-geophysics can play an important role in engineering and construction, as it could affect the construction process if these pre-historic remnants are found on the premises, especially in South Africa.

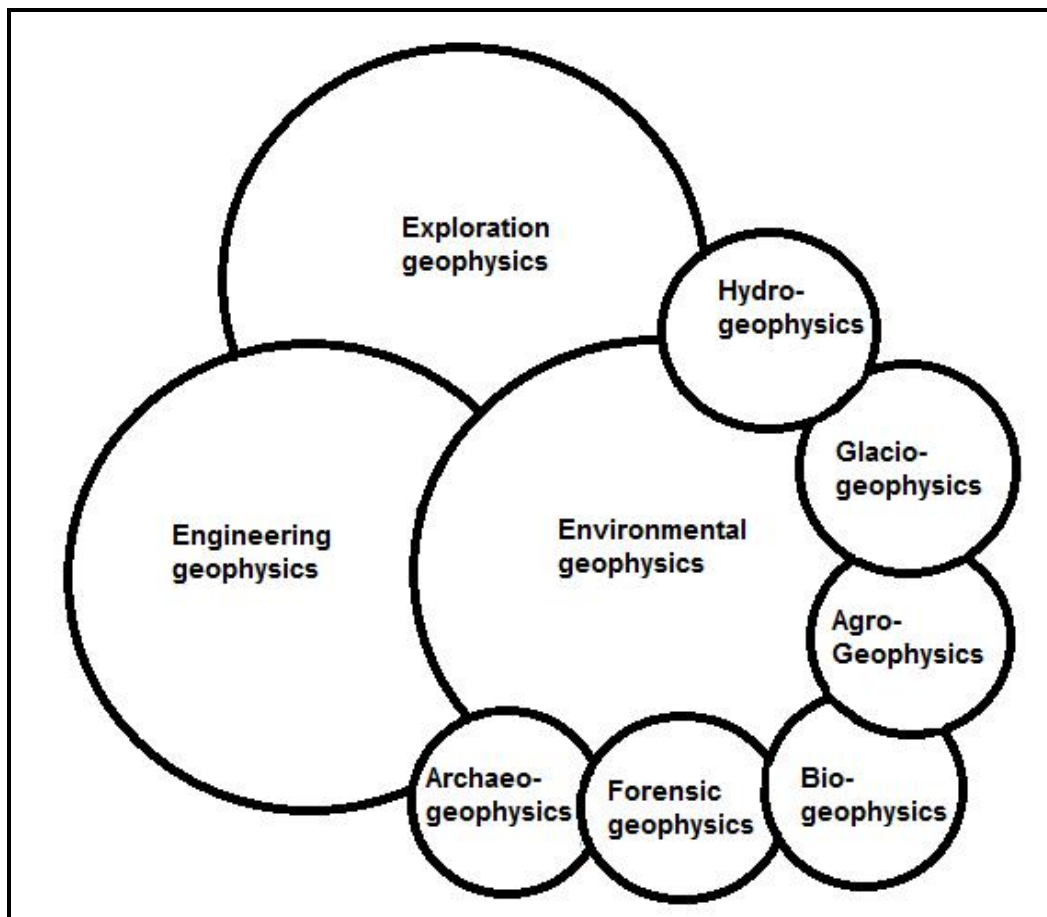


Figure 1: Schematic representation of the three main sub-disciplines of applied geophysics, and the interlocking disciplines of mainly environmental geophysics. Adapted from Reynolds (2011).

1.2.2 The different geophysical techniques

The field of geophysics, and the idea thereof, can be traced back to pre-historic times (Lowrie, 2007; Milsom & Eriksen, 2011). An example given by Lowrie (2007), is the discovery of magnetism by the ancient Greeks dating back to 800 BC, as they discovered a mineral called lodestone (a form of magnetite (Fe_3O_4) which occurs naturally). The magnetic properties of lodestone became known to the Chinese around 300 BC, where they used this naturally magnetic mineral to create a very simple and primitive form of the compass (Lowrie, 2007). Through the discovery of the compass, it was found much later on that the specific alignment of the compass was due to a natural phenomenon caused by the Earth itself, this phenomenon was magnetism and the natural magnetic field of the Earth (Lowrie, 2007). Lowrie (2007) states that this discovery played a pivotal role in the understanding of terrestrial magnetism, which in turn lead to the understanding and study of magnetism in geophysics.

The widespread use of geophysics in everyday studies and investigations, was mainly due to the development of modern geophysical apparatuses in the early to mid-twentieth century (Milsom & Eriksen, 2011). This sudden drive to develop geophysical techniques and apparatuses were mostly due to mineral- and fossil fuel (mostly oil) exploration, which was based on the targets being up to several kilometres beneath the surface of the earth (Milsom & Eriksen, 2011). Many of the apparatuses utilised in the fields of engineering- and environmental geophysics were based on these above-mentioned geophysical techniques, but were modified and adapted to be used for near surface investigations - which, as mentioned previously, implies depths of 100 metres or less (Milsom & Eriksen, 2011).

The key and main focus of any successful geophysical investigation is being able to measure contrasts, or large differences in the area of study (Kearey *et al.*, 2013; Milsom & Eriksen, 2011; Reynolds, 2011). These contrasts measured refers to the difference in physical properties of the surrounding material (sediment, rocks, voids and moisture content) and the target in question (Kearey *et al.*, 2013; Milsom & Eriksen, 2011; Reynolds, 2011). The type of investigation determines what type of contrasts could be expected, or what contrasts one is looking for. A good example is in the case of possible saltwater contamination of subsurface water bodies, where there would be an anomaly or contrast in EC between uncontaminated water and salt contaminated water. The reason for this contrast would be due to the difference of the measured EC in the saltwater and freshwater, where the saltwater would show a much higher EC than the freshwater (Benson *et al.*, 1997; De Franco *et al.*, 2009; Slater & Sandberg, 2000). This method could not only be used to measure the extent of saltwater pollution, but also to measure hydraulic conductivity of subsurface materials or aquifers, by using salt tracers to trace the distance travelled in a set amount of time (Jardani *et al.*, 2013; Slater & Sandberg, 2000).

The most common methods and the properties utilised by these techniques are shown in Table 1. The most common geophysical techniques used are electrical (which includes resistivity and conductivity, self-potential, induced polarisation, EM and ground penetrating radar (GPR)), magnetic, radiometric, gravity and seismic (Kearey *et al.*, 2013; Milsom & Eriksen, 2011). The physical properties utilised by these geophysical techniques are mostly EC, magnetic susceptibility, radioactivity, density and elasticity (Kearey *et al.*, 2013; Milsom & Eriksen, 2011). As mentioned above, the type of investigation will determine which techniques will be used, and this is based on the physics of the problem at hand (Milsom & Eriksen, 2011). Therefore, it is important to choose the correct technique to use (as not all the techniques are necessarily suitable), although in many cases the best option is to use a combination of different techniques to effectively investigate the problem at hand (Milsom & Eriksen, 2011).

Furthermore, these geophysical techniques can be classified as either being an active- or passive geophysical surveying method (Kearey *et al.*, 2013; Milsom & Eriksen, 2011; Reynolds, 2011). Active methods make use of signals that are produced artificially and then transmitted into the subsurface (Kearey *et al.*, 2013; Reynolds, 2011). The generated signals then interact with the surrounding materials, and the altered signals are then picked up (by the receivers) and can be processed, displayed and interpreted (Kearey *et al.*, 2013; Reynolds, 2011). Examples of active methods are those that use EM-, electric- and radioactive properties (Kearey *et al.*, 2013; Milsom & Eriksen, 2011; Reynolds, 2011). Active methods can generally be used for more detailed analyses of the subsurface with much higher resolution, but cannot necessarily be used for deep subsurface investigations (Kearey *et al.*, 2013). Passive methods, on the other hand, are methods that utilise natural signals, or fields, that are generated by, and associated with, the Earth (Kearey *et al.*, 2013; Reynolds, 2011). Geophysical techniques that utilise the natural signals, or fields, of the Earth, are electrical-, magnetic-, EM- and gravitational techniques (Kearey *et al.*, 2013; Milsom & Eriksen, 2011; Reynolds, 2011). Passive methods can be used for investigations that need to be done at much greater depths, but cannot effectively be used for very high resolution and detailed studies (Kearey *et al.*, 2013).

Table 1: A summary of the most common geophysical techniques, the physical properties utilised, whether it is an active- or passive method and the parameters measured, adapted from Milsom and Eriksen (2011) and Kearey et al. (2013).

GEOPHYSICAL TECHNIQUE	PHYSICAL PROPERTY / PROPERTIES	ACTIVE / PASSIVE	PARAMETERS MEASURED
Electrical			
Resistivity and conductivity	Electrical resistivity and conductivity	Active	DC electric current
Self-potential	Electrical conductivity	Passive	Electrical potential
Induced polarisation	Electrical resistivity	Active	Pulsed electric current
Electromagnetic	Electrical resistivity and conductivity	Active/Passive	Response to electromagnetic waves
Ground penetration radar	Dielectric constant	Active	Reflected radar pulses and the travel times thereof
Magnetic	Magnetic remanence and susceptibility	Passive	Spatial differences in the strength of the Earth's magnetic field
Radiometric	Radioactivity	Active/Passive	Artificial or natural radioactive sources
Gravity	Density	Passive	Spatial differences in the strength of the Earth's gravitational field
Seismic	Elasticity and density	Active/Passive	Travel times of refracted /reflected seismic waves

1.3 HYPOTHESIS

It is hypothesised that there will be a positive statistical probability that the different methods and apparatuses used in this study – CMD Electromagnetic Conductivity Meters (CMD Mini-Explorer and CMD Explorer), the CPN 501DR Depthprobe (Neutron probe), the Diviner 2000 and the samples analysed for volumetric water content – would yield similar and accurate results when the different datasets are analysed and compared. It is further hypothesised that the different apparatuses (used to measure SMC) will vary in terms of cost-, labour- and time efficiency, and would therefore influence the suitability of using these apparatuses in different circumstances.

1.4 RESEARCH AIMS AND OBJECTIVES

1.4.1 Aims

The primary aim of this study was to compare the different geophysical apparatuses and methods with each other, to determine whether or not there would be similarities in the data and results. Furthermore, this study aims at locating and discussing areas of concern. The final aim of this study was to determine the effectiveness and efficiency of the apparatuses used.

1.4.2 Objectives

- The comparison of the different geophysical apparatuses and methods will be done by statistical analyses (both T-tests and ANOVA analyses) of data obtained throughout the course of the study. Visual comparisons will also be made, to substantiate the statistical findings.
- Areas of concern, with abnormally high or -low soil moisture content, will be delineated by looking for anomalies and contrasts in the data.
- The effectiveness and efficiency of the apparatuses will be determined by looking at the advantages and disadvantages of each apparatus used. The scale- and purpose of use will then be taken into consideration to determine which apparatus would be the best suited for different circumstances.

1.5 CHAPTER DIVISION

Chapter 1 – Conceptualisation of the project: In this chapter, the background, introduction, hypothesis, research aims and -objectives, and outline of the project was given. Together with this, the chapter also served as a proposal for the study.

Chapter outlay: Background; Introduction; Hypothesis; Research aims and objectives; Chapter division.

Chapter 2 – Literature review: This chapter serves as a detailed literature study, where soil moisture content, factors influencing soil measurements, the most common techniques and methods used for measuring soil moisture content, as well as the gap in knowledge were discussed. The techniques and apparatuses used in this study were discussed and described in detail.

Chapter outlay: Introduction; Soil moisture content; Electromagnetic conductivity meters (CMD); CPN 501DR Depthprobe (Neutron probe); Diviner 2000 (Diviner); The gap in knowledge.

Chapter 3 – Materials and methods: In this chapter, the area of study, materials and methodology used in this study were described. Furthermore, the analytical techniques and software used were mentioned and described.

Chapter outlay: Introduction; Study area; Methods; Monitoring and assessments; Statistical processing methods.

Chapter 4 – Results and discussion: This chapter contains the results found throughout the study, and the discussion thereof.

Chapter outlay: Introduction; Results and discussion.

Chapter 5 – Conclusions: This chapter concludes the study and summarises the results and discussions. The recommendations for further research were also given in this chapter.

Chapter outlay: Introduction; Conclusions; Recommendations for further study.

Chapter 6 – Project management: In this chapter, the time management of the projects was discussed (with the use of a Gantt chart), together with drawbacks, and how these problems were dealt with.

Chapter 7 – References: This chapter shows all the appropriate literature used to conduct this study.

Chapter 8 – Appendices: This chapter shows all the appendices, where appropriate, which includes the raw and processed data.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, soil moisture content, water, the factors influencing soil measurements and some of the most common methods for measuring SMC were mentioned and briefly discussed. A detailed study was conducted on the three methods used in this study namely the CMD Electromagnetic Conductivity meter, the CPN 501DR Depthprobe and the Diviner 2000. The gap in knowledge was also discussed.

2.2 SOIL MOISTURE CONTENT (SMC)

SMC is a term used to describe the amount of moisture or water present in soil, typically present in pore spaces between soil particles (Balaghi *et al.*, 2018; Dobriyal *et al.*, 2012; Gregorich & Carter, 2007; Zhang *et al.*, 2019). SMC forms part of a three phase system, consisting of a solid phase (the soil matrix), a liquid phase (water) and a gaseous phase (soil atmosphere) (Hillel, 2003; Malajner *et al.*, 2019; S.U. *et al.*, 2014; Smith & Mullins, 2001). The soil matrix consists of particles with varying mineralogical and chemical compositions, as well as varying shapes, orientations and sizes (Hillel, 2003; Malajner *et al.*, 2019). The solid soil matrix also includes amorphous material such as organic matter, which binds to mineral grains resulting in aggregates (Hillel, 2003; Malajner *et al.*, 2019). The occurrence and organisation of these solid components determines the pore spaces in soil, where air and water are transmitted and retained (Hillel, 2003). The composition of the liquid phase and gaseous phase vary in both space and time, (Hillel, 2003). Although the three phases of soils are generally presented as being roughly 50% solids and 50% pore space (i.e. 25% liquid and 25% gaseous), these ratios are not fixed as they continuously vary – which depend on factors such as soil management, weather, vegetation types and vegetation cover (Hillel, 2003).

2.2.1 Water

The key to understanding SMC is to understand water, what it is and how it acts. Planet Earth is known and described as the planet of life, and this is due to the amount and availability of water (Ahuja, 2016; Hillel, 2003; Manahan, 2010; Tölgyessy, 1993). Water – a simple molecule consisting of one oxygen- and two hydrogen atoms – has

been the dedicated subject of many studies and textbooks, e.g. Ahuja (2016), Ahuja (2015), Kegley and Andrews (1998); Li and Chen (2006), Manahan (2010); Maréchal (2007); Rao (2008); Sarai (2005); and Tölgyessy (1993) to name a few. For this reason, water and the chemistry thereof will only be discussed very briefly, because the anomalous and unusual nature of this molecule could be seen as a study on its own (Hillel, 2003). This common molecule, making up around 70% of the Earth's surface, has been puzzling researches and mankind for centuries (Ahuja, 2016; Hillel, 2003; Manahan, 2010). Looking at the fact that 70% of the Earth's surface is made up of water, the oceans makes up roughly 97% of this water, the remaining three percent of the available fresh water is present as gas (water vapour), in lakes, rivers, glaciers and below ground (groundwater and SMC) (Ahuja, 2016; Hillel, 2003). Of this three percent, a mere 0.06% of fresh water is readily accessible (Ahuja, 2016).

At 20°C a cubic meter of water (H₂O) in the liquid phase, consists of about 3.4×10^{28} molecules (of which has a diameter of roughly 3×10^{-10} meter) (Hillel, 2003). Both hydrogen (H) and oxygen (O) has three isotopes, which are H¹, H², H³ and O¹⁶, O¹⁷, O¹⁸ respectively (Hillel, 2003). H¹ and O¹⁶ are the most common isotopes of hydrogen and oxygen, where the other isotopes of both atoms are rather rare (Hillel, 2003). A hydrogen atom is comprised of one proton (which is positively charged) and one electron (which is negatively charged), an oxygen atom, on the other hand, is comprised of a nucleus with eight protons and eight neutrons that is surrounded by eight electrons (Hillel, 2003). With hydrogen having only one electron in the outer shell (meaning that H lacks one electrons in the outer shell) and oxygen having six electrons in the outer shell (thus lacking two electrons), two hydrogen atoms can bond with one oxygen forming a single water molecule (Hillel, 2003). The reason for the strong intermolecular forces in water (as a liquid), is due to the arrangement of the electrons between hydrogen and oxygen in a water molecule (where an oxygen atom shares a pair of electrons with both hydrogen atoms), resulting in the electrical polarity of water molecules (Hillel, 2003).

In a water molecule, the H–O–H bond is at an angle of 104.5° with a partial negative charge on the oxygen and a partial positive charge on each hydrogen (Hillel, 2003). This partial positive charge on the hydrogen atom results in each hydrogen bonding with other oxygen atoms (with partial negative charges), and this is called a hydrogen bond (Hillel, 2003). These hydrogen bonds lead to each water molecule bonding with four other water molecules (Hillel, 2003). This structure is best seen with ice crystals,

but when ice melts, this structure partially breaks and additional water molecules can enter the intermolecular spaces (where each water molecule could then have more than four neighbouring molecules) (Hillel, 2003). For this reason, liquid water is denser than ice (water in a solid state) – leading to the phenomenon where ice floats on top of water (Hillel, 2003). This is seen in nature where the top of a dam or lake is frozen, but the water below the sheet of ice is still liquid (Hillel, 2003).

The fact whether water is in a solid, liquid or gaseous state has been mentioned several times in the description above. This is of importance, because water behaves very differently in the different states – which is as a solid (ice), liquid or gas (water vapour) (Hillel, 2003). Water molecules in the gaseous state are mostly independent from each other and occurs as monomers (single water structures $(\text{H}_2\text{O})_1$) (Hillel, 2003). When monomers collides with other monomers, it can cause molecules to fuse and form dimers $((\text{H}_2\text{O})_2)$ or trimmers $((\text{H}_2\text{O})_3)$, but these two combinations are quite rare (Hillel, 2003). At the complete opposite, water in the solid state (ice) forms orderly structured lattices that forms in tetrahedral configurations that could be schematically represented by bound hexagonal rings (Hillel, 2003). Depending on the temperature and pressure and which water freezes, nine alternative forms of ice can occur (Hillel, 2003). Finally, the well organised structure of ice does not completely break down when it melts to form liquid water, due to the polarity of the molecules and hydrogen bonds binding water molecules together (Hillel, 2003).

For water, hydrogen bonds need to be broken for a solid to transition into a liquid, as well as the transition for liquid to gas (Hillel, 2003). The opposite is true for freezing (a liquid turning into a solid) and condensation (a gas turning into a liquid), where hydrogen bonds must be re-established (Hillel, 2003). For this reason, relatively high temperatures (or energy) are required for these transitions to take place (Hillel, 2003). Thus, to thaw one kilogram of ice 3.35×10^5 Joules (J) are required (Hillel, 2003). For water to boil (liquid turning into a gas at 100°C and at atmospheric pressure) 2.26×10^6 Joules per kilogram are absorbed (Hillel, 2003). Lastly, ice could be transitioned directly into a gas, and this is called sublimation (Hillel, 2003).

2.2.2 Factors influencing soil measurements

Understanding soil and SMC is essential, as SMC plays a pivotal role in a whole array of disciplines (e.g. agriculture, hydrology, environmental rehabilitation, engineering,

waste management, forestry, ecology and geology) and investigations (e.g., biological, ecological, biogeochemical, microbiological, chemical and biophysical) (Balaghi *et al.*, 2018; Bittelli, 2011; Cooper, 2016; Dobriyal *et al.*, 2012; Fang *et al.*, 2019; Malajner *et al.*, 2019; Palaparthi *et al.*, 2017; S.U. *et al.*, 2014; Smith & Mullins, 2001; Zhang *et al.*, 2019). The SMC also affects soil properties such as nutrient transportation, infiltration, runoff, water flow (above and below ground), aquifer and groundwater recharge, shrinkage, swelling, consistency, density, erosion and plant available water (Balaghi *et al.*, 2018; Bittelli, 2011; Charlesworth, 2005; Lee & Kim, 2019b; Palaparthi *et al.*, 2017).

SMC affect soils and soil properties in various ways, but to measure SMC one has to take into consideration the factors that affect SMC. The factors (spatial and temporal) that could influence SMC and the measurement thereof are listed below (Azoor *et al.*, 2019; Chesworth, 2007; Grillakis, 2019; Gwak & Kim, 2017; Lal, 2006; Lee & Kim, 2019a; Legates *et al.*, 2011; Nippgen *et al.*, 2011; Reynolds, 1970; Robock *et al.*, 2000; Rosenbaum *et al.*, 2012; Vereecken *et al.*, 2014; Western *et al.*, 1998; Zhao *et al.*, 2012; Zucco *et al.*, 2014):

- Surface and landscape topography
- Elevation
- Vegetation type and variability
- Evapotranspiration
- Land use (irrigation, compaction and the overall condition of the soil – such as degree of erosion, pH and nutrient status)
- Soil types and classification (soil depth, soil horizons, texture, structure, soil bulk density, mineralogy, underlying geology, particle size distribution, aggregates, organic matter, microorganisms, as well as sand-, silt- and clay content)
- Saturation state of the soil
- Soil temperature
- Ambient temperature
- Precipitation
- Depth of water table
- Drainage
- Leaching

- Salinity
- Possible ore deposits (e.g. gold, platinum and iron ore)
- Pollution (e.g. metals, salts and acid mine drainage)

2.2.3 Direct and indirect measurement of SMC

SMC can be measured in numerous ways, with different techniques, methods and apparatuses such as those mentioned in Table 1 (Robock, 2015; Vereecken *et al.*, 2014). These methods and apparatuses range from the basic gravimetric method to complicated electrical apparatuses and satellite remote sensing techniques (Robock, 2015; Uniyal *et al.*, 2017; Vereecken *et al.*, 2014). Some of the most common techniques and apparatuses used for SMC measurement will be briefly discussed (as a full research- or literature review of all available techniques and methods are beyond the scope of this study). The techniques and methods used in this study will be mentioned in this section, but not discussed in detail - as the techniques used are discussed in detail later in this chapter.

2.2.3.1 Direct measurements of SMC

There are two methods for measuring SMC, namely direct- and indirect methods (Dobriyal *et al.*, 2012; Muñoz-Carpena *et al.*, 2004). The direct methods are gravimetric- and volumetric measurements (Dobriyal *et al.*, 2012; Muñoz-Carpena *et al.*, 2004; Uniyal *et al.*, 2017). The gravimetric method (used in this study), also referred to as the thermostat-weight technique and thermo-gravimetric, is a very old and trusted method (Robock, 2015; S.U. *et al.*, 2014). With this method, soil samples are taken by hand (with the use of a soil auger drill) at set depths (e.g. 10 or 20 centimetres) (Bittelli, 2011; Robock, 2015; S.U. *et al.*, 2014). The samples taken in the field are weighed (in the wet condition), after which they are oven dried for at least 24 hours at 105°C (Bittelli, 2011; Dobriyal *et al.*, 2012; Hillel, 2003; Muñoz-Carpena *et al.*, 2004; Robock, 2015; S.U. *et al.*, 2014). After oven drying, the samples are then weighed again (in the dry condition), where the wet sample weight is then subtracted from the dry sample weight to give the gravimetric water content of the soil (Bittelli, 2011; Dobriyal *et al.*, 2012; Hillel, 2003; Muñoz-Carpena *et al.*, 2004; Robock, 2015; S.U. *et al.*, 2014). Thus, gravimetric water content is defined as the ratio of the weight of water (in a soil sample prior to oven drying) to the weight of the same sample after drying (Bittelli, 2011; Dobriyal *et al.*, 2012; Hillel, 2003; S.U. *et al.*, 2014). The

gravimetric water content can also be expressed as volumetric water measurements (ratio of volume of water present in a volume of soil) by simply multiplying the gravimetric measurements with the soils' bulk density, and then dividing that value by the density of water (Bittelli, 2011; Hillel, 2003; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014).

2.2.3.2 *Indirect techniques for measurement of SMC used in this study*

As mentioned in Chapter 1, the apparatuses used in this study was the CMD Mini-Explorer, CMD Explorer, Neutron probe and Diviner 2000. The CMD Mini-Explorer and CMD Explorer are both electromagnetic probes that rely on the principles of electromagnetic induction, which is discussed in detail later in this chapter (Bonsall *et al.*, 2013; Doolittle & Brevik, 2014; Robinet *et al.*, 2018; Vereecken *et al.*, 2014). There is an array of quality EM products available for use like the DUALEM-1, DUALEM-2, EM38-MK2, Profiler EMP-400, EM31 and the whole range of the CMD products (to name but a few) (Bonsall *et al.*, 2013; Doolittle & Brevik, 2014; Robinet *et al.*, 2018; Vereecken *et al.*, 2014).

The Neutron probe is a neutron scattering method that measures SMC through neutron thermalisation and is discussed in more detail below (Balaghi *et al.*, 2018; Bittelli, 2011; Charlesworth, 2005; Dobriyal *et al.*, 2012; Lee *et al.*, 2018b; Muñoz-Carpena *et al.*, 2004; Robock, 2015; S.U. *et al.*, 2014; Uniyal *et al.*, 2017). Some examples of neutron scattering apparatuses are the CPN 501 Depthprobe and the CPN 503DR Depthprobe.

The Diviner 2000, a dielectric technique, uses frequency domain reflectometry and is also called a capacitance probe (Charlesworth, 2000; Charlesworth, 2005; Dobriyal *et al.*, 2012; S.U. *et al.*, 2014; Samson *et al.*, 2016; Sentek.Pty.Ltd, 2009). Other than the Diviner 2000, Sentek has an array of frequency domain reflectometry apparatuses (i.e. EnviroSCAN, EnviroSMART, TriSCAN and EasyAg) and there is a lot of different products available such as the C-Probe and the C-Probe III (Charlesworth, 2005; Dobriyal *et al.*, 2012; Muñoz-Carpena *et al.*, 2004; Robock, 2015; S.U. *et al.*, 2014; Vereecken *et al.*, 2014).

2.2.3.3 *Other common indirect techniques for the measurement of SMC*

Another dielectric technique of measuring SMC is time domain reflectometry (TDR) (Charlesworth, 2005; Curioni *et al.*, 2018; Dobriyal *et al.*, 2012; Lee *et al.*, 2018a; Lee *et al.*, 2018b; Michel *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014;

Samson *et al.*, 2016; Scheuermann *et al.*, 2019; Vereecken *et al.*, 2014). TDR is similar to frequency domain reflectometry in certain aspects, as it also measures the dielectric properties of soils (Charlesworth, 2005; Curioni *et al.*, 2018; Dobriyal *et al.*, 2012; Lee *et al.*, 2018a; Lee *et al.*, 2018b; Michel *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014; Samson *et al.*, 2016; Scheuermann *et al.*, 2019; Vereecken *et al.*, 2014). The dielectric permittivity of soils are known to have a strong relation to SMC, due to the contrasts that exist between the dielectric permittivity of water and the soils' other constituents (Charlesworth, 2005; Curioni *et al.*, 2018; Dobriyal *et al.*, 2012; Lee *et al.*, 2018a; Lee *et al.*, 2018b; Michel *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014; Samson *et al.*, 2016; Scheuermann *et al.*, 2019; Vereecken *et al.*, 2014). This contrast in permittivity results in the travel time of these wavelengths being depended on the volumetric water content in soils (Charlesworth, 2005; Curioni *et al.*, 2018; Dobriyal *et al.*, 2012; Lee *et al.*, 2018a; Lee *et al.*, 2018b; Michel *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014; Samson *et al.*, 2016; Scheuermann *et al.*, 2019; Vereecken *et al.*, 2014). TDR probes (more specifically the receivers) measures the dielectric properties of soil by determining the velocity of microwaves – part of the electromagnetic radiation spectrum – emitted by the transmitter (Charlesworth, 2005; Curioni *et al.*, 2018; Dobriyal *et al.*, 2012; Lee *et al.*, 2018a; Lee *et al.*, 2018b; Michel *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014; Samson *et al.*, 2016; Scheuermann *et al.*, 2019; Vereecken *et al.*, 2014). The velocity of the microwaves are calculated by measuring the time that the waves travelled through a TDR probe (of a known length). The TRASE System 1, MiniTRASE, Campbell Scientific TDR100, Aqualex and Gro-Point are all common TDR probes (Charlesworth, 2005).

Electrical resistivity (also referred to as electrical conductivity) is a common geophysical method (Bittelli, 2011; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). This method can be used to determine subsurface geological and soil strata, which is determined by the different electrical resistivity (or conductivity) of different layers below ground (Bittelli, 2011; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). This method can also be used for measuring SMC, and is called the soil resistivity sensor technique (Bittelli, 2011; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). This is made possible due to the fact that soil resistivity decreases as SMC increase (or soil conductivity increases as SMC increases) (Bittelli, 2011; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). Four electrodes are inserted into the ground, where two

electrodes inject an electrical current into the soil and the other two electrodes measure the resulting potential difference (Bittelli, 2011; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). An average heterogeneous electrical conductivity is produced by the measured potential difference in current, resulting in a measurement of apparent conductivity (Bittelli, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). The most common four probe resistance methods include the Wenner array, Schlumberger array and the Dipole-dipole array (Bittelli, 2011; Milsom & Eriksen, 2011).

Ground penetrating radar is a method that makes use of high frequency electromagnetic waves (typically between 1 Mhz and 1 Ghz), and how these waves are transmitted and reflected in the subsurface (Dobriyal *et al.*, 2012; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). Measurements by GPR techniques provide insight (or information) about the subsurface materials' permittivity (Dobriyal *et al.*, 2012; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). This method measures the time it takes a ground wave to travel from the source of the wave to the receiver, and travel times are correlated to the dielectric constant of the SMC measurement (Dobriyal *et al.*, 2012; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014). GPR is a common method, because it delivers high-resolution results, it is a non-invasive method and can be used to measure large areas of the subsurface and the surface (Dobriyal *et al.*, 2012; Milsom & Eriksen, 2011; S.U. *et al.*, 2014; Vereecken *et al.*, 2014).

Another method of SMC measurement is the dual probe heat pulse (DPHP) sensor technique (Palaparthi *et al.*, 2017; Robock, 2015; S.U. *et al.*, 2014). The DPHP technique consists of two probes – the heater probe and the temperature sensing probe – that are inserted into the soil at a known distance from each other (Palaparthi *et al.*, 2017; Robock, 2015; S.U. *et al.*, 2014). The heater probe is heated up by a voltage pulse for a fixed amount of time and this causes heat to disperse in all directions (Palaparthi *et al.*, 2017; Robock, 2015; S.U. *et al.*, 2014). The temperature probe then measures the rise in temperature, and then determines the change in overall temperature of the soil sample (Palaparthi *et al.*, 2017; Robock, 2015; S.U. *et al.*, 2014). This technique works on the principle that dry soil will have a larger increase of temperature than wet soil (or rather soil with higher SMC), due to the thermal conductivity of water (Palaparthi *et al.*, 2017; Robock, 2015; S.U. *et al.*, 2014).

Tensiometric techniques measure capillary tension (or matric potential) in soils (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014). A tensiometer consists of an airtight tube with a porous ceramic cup, both of which are filled with moisture, at the bottom of the tube (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014). The tube is buried in the soil at the desired depth, and a vacuum gauge is connected at the top of the tube (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014). While the tube is buried in the soil, the moisture from the porous ceramic cup gets in contact with the soil (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014). Due to the porosity of the ceramic cup, the moisture in the cup reaches an equilibrium with the SMC (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014). The vacuum gauge then shows the drop in hydrostatic pressure, caused by the loss of moisture from the air tight tube (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014). This measurement is related to the plant water tension and is therefore also a good measurement of plant stress (Balaghi *et al.*, 2018; Muñoz-Carpena *et al.*, 2004; S.U. *et al.*, 2014).

Optical techniques, such as the polarised light technique, fibre optic sensor technique and near-infrared optical technique, are also used to measure SMC (Bittelli, 2011; S.U. *et al.*, 2014). Shortly, these techniques are based on incident- and reflected light and the characteristics thereof as it passes through soil (S.U. *et al.*, 2014). The polarised light technique works on the principle that the presence of moisture on the surface results in the polarisation of reflected light (S.U. *et al.*, 2014). The fibre optic sensor technique uses an optical fibre that is placed in the soil, and the amount of SMC that is in contact with the fibre influences light attenuation in the fibre (S.U. *et al.*, 2014). Near-infrared optical techniques are based on the principle that several bands in the near-infrared spectrum (especially 1450-, 1940- and 2950 nanometres) are heavily influenced by moisture (S.U. *et al.*, 2014).

With technology getting better, faster and more accessible, remote sensing of SMC has become a much more common method. With remote sensing, it is possible to measure the SMC of larger regions in short periods of time (Balaghi *et al.*, 2018; Robock, 2015; Uniyal *et al.*, 2017; Vereecken *et al.*, 2014). Three common methods are satellite remote sensing of SMC, GPS soil moisture observations and the COsmic-ray Soil Moisture Observing System (COSMOS) (Robock, 2015). Satellite remote sensing measures microwave emissions from soil that are affected by the difference in the dielectric constant between wet- and dry soils (Robock, 2015). With this method,

however, influences such as vegetation cover, surface roughness and surface temperature should be taken into consideration, and measurements cannot be taken under dense vegetation canopies (Robock, 2015). GPS soil moisture observations use GPS satellites that transmit L-band signals, which is also used for navigation (Robock, 2015). Direct microwave signals received by permanently situated GPS receivers (receivers that are mounted on poles or towers) can be used to measure SMC of the soil surface (several tens of centimetres) (Robock, 2015). Lastly, the COSMOS measures the intensity of low-energy cosmic-ray neutrons above the ground, as these neutrons are inversely correlated with SMC (Robock, 2015). With the COSMOS, these neutrons can be measured to determine the average SMC of depths up to 50 centimetres at regions as large as 350 000 m² (Robock, 2015).

2.3 CMD ELECTROMAGNETIC CONDUCTIVITY METERS (CMD)

The CMD Electromagnetic Conductivity Meters (hereon collectively referred to as CMD, or individually referred to as the CMD Mini-Explorer and CMD Explorer) is a product range by GF Instruments. According to Bonsall *et al.* (2013), the range of CMD units (including the CMD Tiny, CMD 1, CMD 2, CMD 4, CMD 4/6, CMD Mini-Explorer and the CMD Explorer) are electromagnetic probes, which are mainly used for geological and environmental studies, and investigations for the detection of geological units and pipes. The popularity of EM methods for geophysical- and hydrogeophysical investigations have increased over the last few decades (Boaga, 2017; Bonsall *et al.*, 2013; Knödel *et al.*, 2007; Schmugge *et al.*, 1980; Shanahan *et al.*, 2015). One of the main reasons for the increase in popularity, is due to the ease with which these EM apparatuses are operated, thereby being very time- and labour effective (Boaga, 2017; Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Knödel *et al.*, 2007). This EM method is quick and easy to use due to the fact that the CMD does not require direct contact with the surface of the Earth, thus resolving the common problems associated with electric current methods (e.g. the lack of contact between the electrodes in arid environments) (Bonsall *et al.*, 2013; Milsom, 2003).

A study done by Bonsall *et al.* (2013), showed that the CMD Mini-Explorer has the potential for accurate and high-quality data, which can be compared to standard electric current methods and magnetic methods. Although ground-based methods (e.g. electrical resistivity tomography) have advantages such as high resolution characterization of soils and the capability of much deeper investigations, it's not always possible to do large scale investigations (Boaga, 2017; Bonsall *et al.*, 2013). This is mainly due to logistical- and

environmental limitations associated with these ground-based methods (Boaga, 2017; Bonsall *et al.*, 2013).

According to Knödel *et al.* (2007), EM methods can be classified either as natural field methods (passive) or controlled source methods (active). Active methods (as in the case of the CMD) are preferred in environmental and geophysical investigations (Bonsall *et al.*, 2013; Knödel *et al.*, 2007). Dual coil systems, which have transmitter (Tx) and receiver (Rx) coils, are important controlled source method instruments for shallow subsurface studies (shallow, referring to metres, rather than tens or hundreds of metres below ground) (Bonsall *et al.*, 2013; Knödel *et al.*, 2007). These active methods can then be further divided into frequency domain electromagnetic methods (FEM) and transient or time domain electromagnetic methods (TEM) (Knödel *et al.*, 2007). For the purpose of this study, the focus will be on FEM, since the CMD functions in the frequency domain.

The Tx and Rx coils (also called loops) are referred to as either being horizontal or vertical, that is according to the plane that the coils' windings lie (Knödel *et al.*, 2007; Milsom, 2003). The configurations of these loops are important, as it affects the penetration depth, sensitivity and resolution of the EM survey (Knödel *et al.*, 2007). As in the case of the CMD Mini-Explorer and CMD Explorer, these apparatuses have three different Tx-Rx coil spacing's (shown in Table 2), which makes it possible to take three simultaneous depth measurements (Shanahan *et al.*, 2015; Simon *et al.*, 2015). Figure 2 shows the four most commonly used source and receiver configurations for FEM methods. Knödel *et al.* (2007) states that the main configurations used, in practice, are a) the horizontal coplanar (Slingram, HCP, HLEM) and b) the vertical coplanar (VCP, VLEM) configurations (see Figure 2). The horizontal orientation of coils result in vertical magnetic dipoles (VMD), and the vertical orientation of coils result in horizontal magnetic dipoles (HMD). Only a few apparatuses allow measurements to be taken with configurations c) and d) (in Figure 2) (Knödel *et al.*, 2007). When considering a FEM method, the most important factors to look at are the resolution- and depth of penetration (Knödel *et al.*, 2007). Therefore, when the resolution of the shallow subsurface is most important, one would use the VLEM configuration, and when depth is of most importance, one would use the HLEM configuration (Knödel *et al.*, 2007).

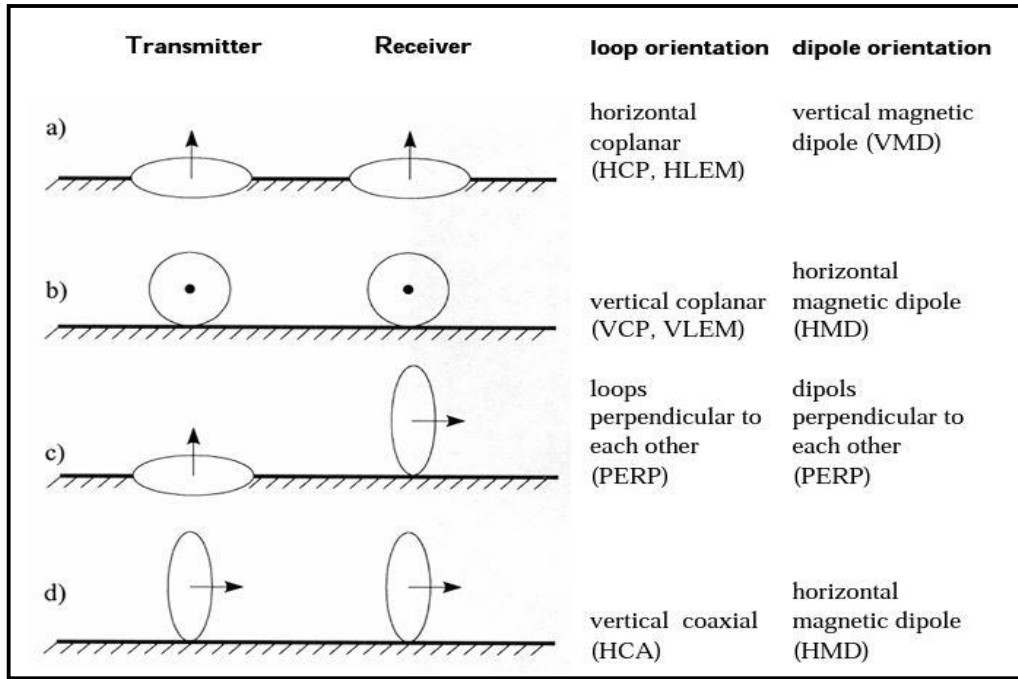


Figure 2: The four most commonly used loop configurations for Tx-Rx FEM methods, after Knödel *et al.* (2007).

Figure 3 is a schematic representation of the principle upon which most commonly used FEM methods are based (Knödel *et al.*, 2007). The Slingram design (a Swedish term used to describe a HCP system) generates an alternating current that passes through the Tx coil, which induces a primary EM field (H_p) through the surface of the Earth (Boaga, 2017; Bonsall *et al.*, 2013; Knödel *et al.*, 2007). These primary fields then pass through the soil and generates eddy currents, with a phase shift, as it encounters conductive material (Boaga, 2017; Bonsall *et al.*, 2013; Knödel *et al.*, 2007). Thereafter, the conductive material produces secondary magnetic fields (H_s) that are then returned to, and measured by, the Rx coil (Boaga, 2017; Bonsall *et al.*, 2013; Knödel *et al.*, 2007).

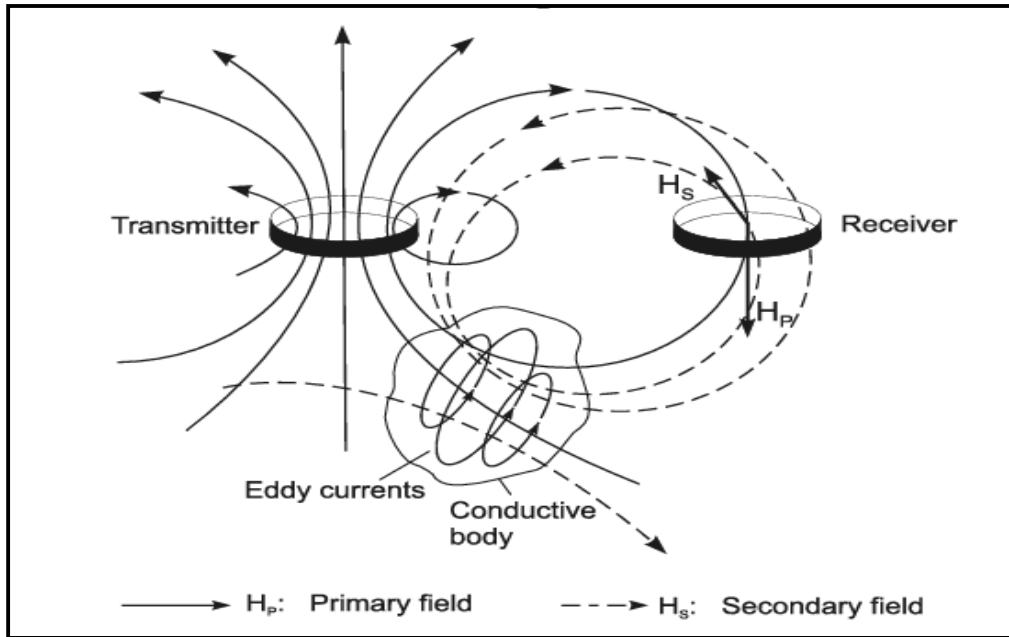


Figure 3: The principle on which EM induction methods function, after Knödel *et al.* (2007).

The strength of H_s is dependent on the EC of the soil, on the frequency at which the apparatus is operated at and on the Tx-Rx coil configuration (Boaga, 2017; Knödel *et al.*, 2007). The phase shift, of H_s , is described to be quadrature or as out-of-phase with H_p , and that value is then observed as a measurement of soil EC (Bonsall *et al.*, 2013; Knödel *et al.*, 2007). Boaga (2017) then states that two values are measured each time; the real, or “in-phase”, component and the imaginary, or “out-of-phase” component (in Figure 4). According to Bonsall *et al.* (2013), the fixed Tx-Rx coil distance in a Slingram apparatus has a larger correlated effect on the penetration depth, than when differing frequencies are used. More modern EM apparatuses, on the other hand, contain multiple Rx coils with variable distances that are separated from the Tx coil, and operates at a single frequency (Bonsall *et al.*, 2013). This allows the apparatus to take measurements at multiple depths (Bonsall *et al.*, 2013). The fact that the frequency, the coil configuration and the approximate height of the sensor above ground is known, makes it possible to calculate the approximate depth of the measurement for each Tx-Rx pair (Bonsall *et al.*, 2013). Two examples of such modern apparatuses, given by Bonsall *et al.* (2013), are the CMD Mini-Explorer and Explorer, and the Dualem-21S (for the purpose of this study, this apparatus is not of importance).

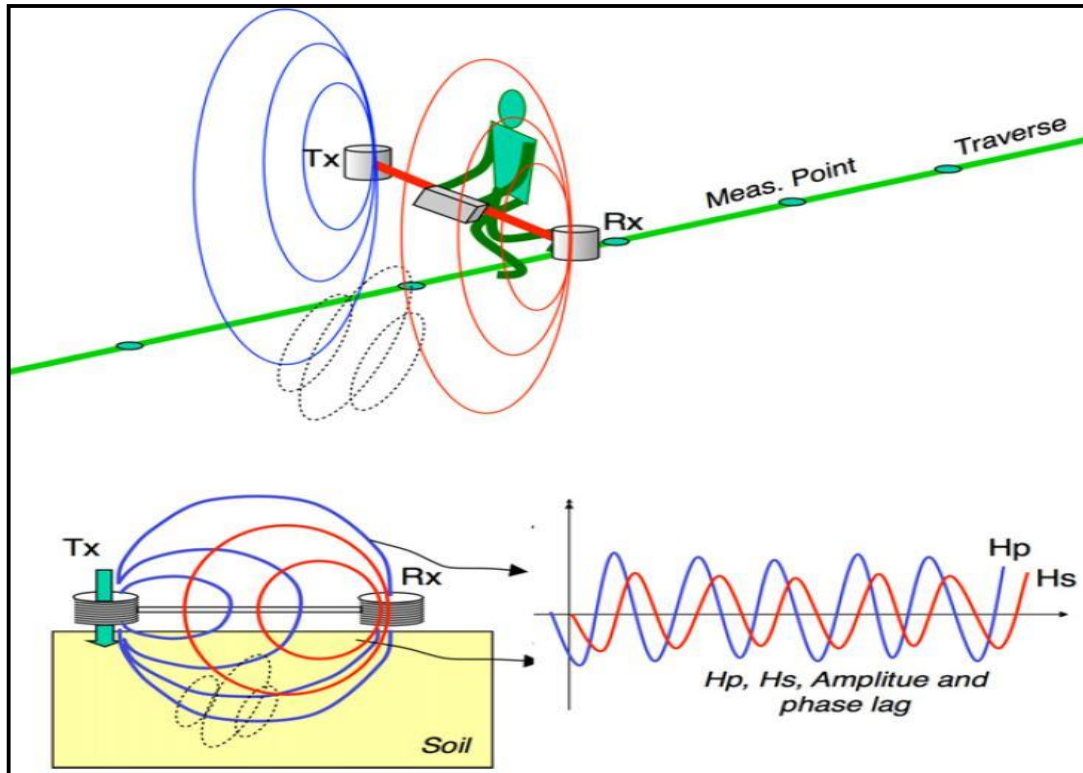


Figure 4: Schematic representation of how the CMD works; showing the primary field (H_p) that is generated by the transmitter (Tx) coil, the eddy currents generated and the secondary field (H_s) that is received and measured by the receiver (Rx) coil. The graph shows the phase lag and amplitude differences between H_p and H_s . Furthermore, two values are recorded at the measurement points, the in-phase and the out-of-phase component, taken from (Boaga, 2017).

The CMD operates at 30 kHz and has three Rx coils which are spaced at a certain distance from the Tx coil (the spacing differs for the CMD Mini-Explorer and the CMD Explorer and is shown in Table 2) (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Shanahan *et al.*, 2015; Simon *et al.*, 2015). The CMD has two coil orientations, HCP (described as full depth) and, when the probe is rotated 90°, VCP (described as half depth) and the effective depths are shown in Table 2 (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Shanahan *et al.*, 2015). Since the CMD operates at 30 kHz, it is defined as a very low frequency (VLF) EM method (Knödel *et al.*, 2007; Shanahan *et al.*, 2015). Figure 5 is a schematic representation of the CMD Mini-Explorer, and shows the HCP and VCP coil orientations, as well as the spacing between the Tx and Rx coils. Although there are overlapping, or nearly overlapping, depths when considering the HCP and VCP orientation (Mini-Explorer at 0.5 and the Explorer at 2.2 and 2.1), the measurements for these overlapping depths will most likely differ (Bonsall *et al.*, 2013). Bonsall *et al.* (2013) states that the reason why these overlapping depth measurements are likely to differ, is due to the two coil orientations that measures different volumes or amounts of earth.

With the CMD Mini-Explorer and Explorer (just like other more modern EM apparatuses) the apparent conductivity (quadrature or out-of-phase) is measured in milliSiemens per metre

(mS/m) with a resolution of 0.1 mS/m and the in-phase ratio is measured in parts per thousand with a resolution of 10 parts per million (ppm) (Bonsall *et al.*, 2013; GF-Instruments, 2016). A major advantage that the CMD Mini-Explorer and Explorer has over Earth resistance surveys and magnetometers, is the fact that the same volume or amount of earth is measured for any point sampled (Bonsall *et al.*, 2013). This is possible, because the co-location of in-phase data and quadrature data is acquired simultaneously (Bonsall *et al.*, 2013).

The CMD Mini-Explorer and CMD Explorer operates very similarly, with just a few exceptions.

- CMD Mini-Explorer: This probe consists of two parts (two orange tubes), which are connected by means of a cable and is tightly secured together by a screw cap connection. This probe is then connected to the control unit by means of Bluetooth (that operates in the GHz band, thus not affecting the operation frequency of the CMD that, as mentioned, is at 30 kHz) (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Simon *et al.*, 2015). This connection, via Bluetooth, makes it possible for the apparatus to be operated on-foot (as shown in Figure 5) or to be towed behind an all-terrain vehicle (ATV) on a sledge (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015). This instrument can be set up within 10 minutes to be operated on foot, and within 20 minutes when mounted on the sledge (as it is necessary to ensure that the apparatus is securely fitted on the sledge) (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015).
- CMD Explorer: This probe consists of four parts (four orange tubes), which are connected in the same manner as the CMD Mini-Explorer. This probe is connected to the control unit by means of a cable. A harness is attached to the probe and the control unit, which is then fitted on the user. This apparatus is used for on-foot surveys, and takes a bit more time to assemble, usually about 10 - 15 minutes.

A GPS (global positioning system) unit is used in conjunction with both the CMD Mini-Explorer and CMD Explorer. This enables the apparatus to automatically take GPS coordinates with each measurement. The CMD automatically compensates for temperature, thus providing an absolute calibration of the apparent conductivity data before the profile or line data is collected – this limits drift that could occur across the dataset (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015). Both these apparatuses can be held level and quite comfortably at a constant height, thus ensuring maximum accuracy and depth of penetration (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015). The measurements can be taken either by means of the “continuous measurement” setting (the operator chooses the time interval between each measurement – 0.1 to 1 second due to a maximum sample rate of 10 Hz) or by means of manual measurements (where a button is pressed each time at the desired location) (Bonsall *et al.*, 2013; GF-Instruments, 2016; Jadoon *et al.*, 2015).

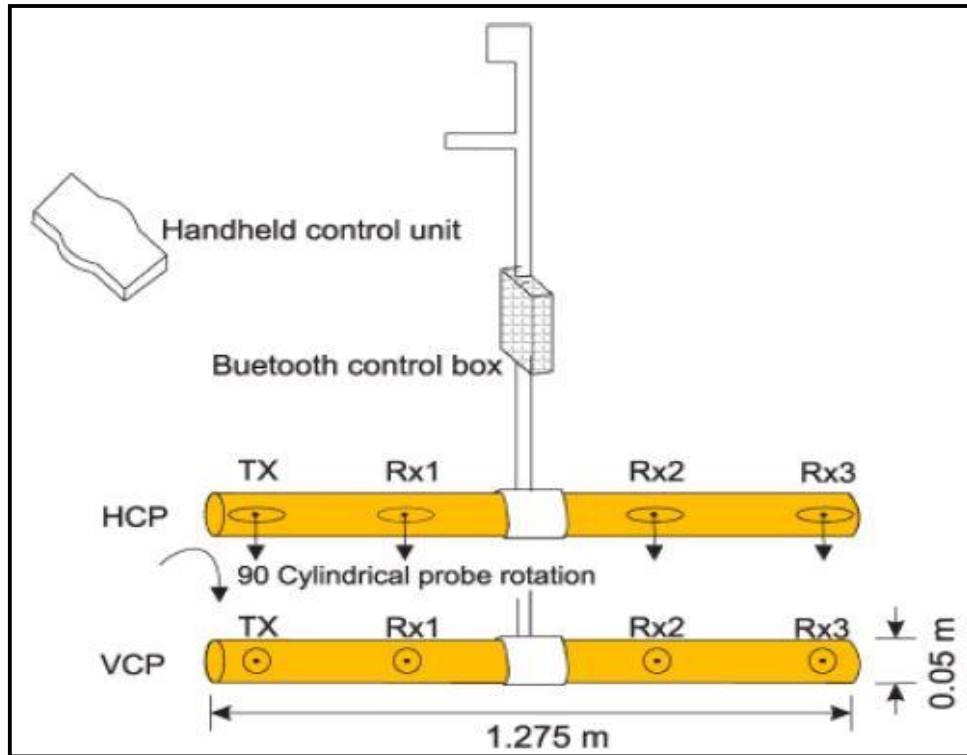


Figure 5: Schematic representation of the CMD Mini-Explorer, showing the horizontal coplanar (HCP) and vertical coplanar (VCP) orientation of the Tx-Rx coils. The receiver coils Rx1, Rx2 and Rx3 are 0.32 m, 0.71 m and 1.18 m from the transmitter coil, after Jadoon et al. (2015) and Bonsall et al. (2013).

Table 2: The technical specifications of the CMD Mini-Explorer and CMD Explorer (Bonsall et al., 2013; GF-Instruments, 2016; Jadoon et al., 2015).

Probe	Effective Depth for HCP (m)	Effective Depth for VCP (m)	Rx distance from Tx (m)	Unit weight (kg)
CMD Mini-Explorer	0.5	0.25	0.32	2.0
	1.0	0.5	0.71	
	1.8	0.9	1.18	
CMD Explorer	2.2	1.1	1.48	8.0
	4.2	2.1	2.82	
	6.7	3.3	4.49	

For the purpose of this study, the measurements taken (by the CMD Mini- Explorer and Explorer) are in the HCP coil orientation. The reason being that it is expected that there are palaeochannels on the site under investigation, and more specifically on the pivot under investigation, that can influence the underground water flow. These palaeochannels are expected to be at a depth of at least one metre or deeper. Although these palaeochannels are not the focus of this study, the presence thereof could greatly affect the flow of underground water, and therefore could affect the water management plan. Thus, if anomalies that represents palaeochannels are found, it could greatly assist in the correct planning of the water management system. It could also likely explain some issues that the farmer is having on the

specific pivot. One of these problems are that the Eastern half of the pivot tends to be very dry, and the Western half tends to be extremely wet.

2.4 CPN 501DR DEPTHPROBE (NEUTRON PROBE)

Chanasyk and Naeth (1996), Schmugge *et al.* (1980) and Smith and Mullins (2001) state that the Neutron probe was initially developed in 1950. The Neutron probe is a nuclear technique, which is described as a neutron scattering method. With the neutron scattering method, the soil moisture is indirectly measured (Chanasyk & Naeth, 1996; Schmugge *et al.*, 1980). The SMC is estimated by means of measuring thermal or slow neutron density (Chanasyk & Naeth, 1996; Schmugge *et al.*, 1980; Smith & Mullins, 2001). Neutron thermalisation is when fast moving neutrons with a high amount of energy (from the radioactive source in the probe) are thermalised, or slowed, when coming into contact with the soil due to elastic collisions with hydrogen nuclei in H₂O and other minerals (Chanasyk & Naeth, 1996; McKay & Acomb, 1996; Schmugge *et al.*, 1980; Smith & Mullins, 2001; Tokumoto *et al.*, 2012). The receiver or detector then counts these thermalized neutrons that returns to the probe (Smith & Mullins, 2001; Tokumoto, 2013; Tokumoto *et al.*, 2012). The average amount of energy lost due to these collisions are much larger when these neutrons collide with lighter elements (in the case of soils, this is mostly hydrogen) compared to collisions with heavier atoms (Chanasyk & Naeth, 1996; Schmugge *et al.*, 1980; Smith & Mullins, 2001). The result being that, in soil, hydrogen slows down fast-moving neutrons a lot more effectively than other elements present (Chanasyk & Naeth, 1996; Schmugge *et al.*, 1980; Smith & Mullins, 2001).

The density of this cloud, which is a result of thermalized neutrons, is a function of the SMC present in the vapour-, liquid- or solid phase (Chanasyk & Naeth, 1996; McKay & Acomb, 1996; Schmugge *et al.*, 1980). The amount of thermalized neutrons that returns to the detector per unit of time over a known soil volume (or known volume of influence) are then counted, where the SMC is then determined by using a standard curve – volumetric water content (θ) versus the Count Ratio (P) (Biswas & Si, 2013; Chanasyk & Naeth, 1996; McKay & Acomb, 1996; Schmugge *et al.*, 1980). Firstly, volumetric water content is determined by gravimetric water Content (V_w) over the total volume of the soil sample (V_t) (Biswas & Si, 2013; Sparks, 2003).

Equation 1: Volumetric water content.

$$\theta = V_w / V_t$$

Secondly, the Count Ratio (P) is determined by the counts taken in the medium (N) over the counts taken as the reference (N_s) (Biswas & Si, 2013; Smith & Mullins, 2001; Tokumoto, 2013; Tokumoto *et al.*, 2012).

Equation 2: Formula used to determine the Count Ratio of the Neutron probe.

$$P = N/N_s$$

It is important to note that the sphere of influence, of the measurements taken by the probe, is affected by the density and SMC of the soil (Schmugge *et al.*, 1980; Smith & Mullins, 2001). The reference counts (N_s) are taken prior to each profile reading, and is done by taking a measurement when the probe is still in the protective casing (or shield box as shown in Figure 6) (Chanasyk & Naeth, 1996; McKay & Acomb, 1996).

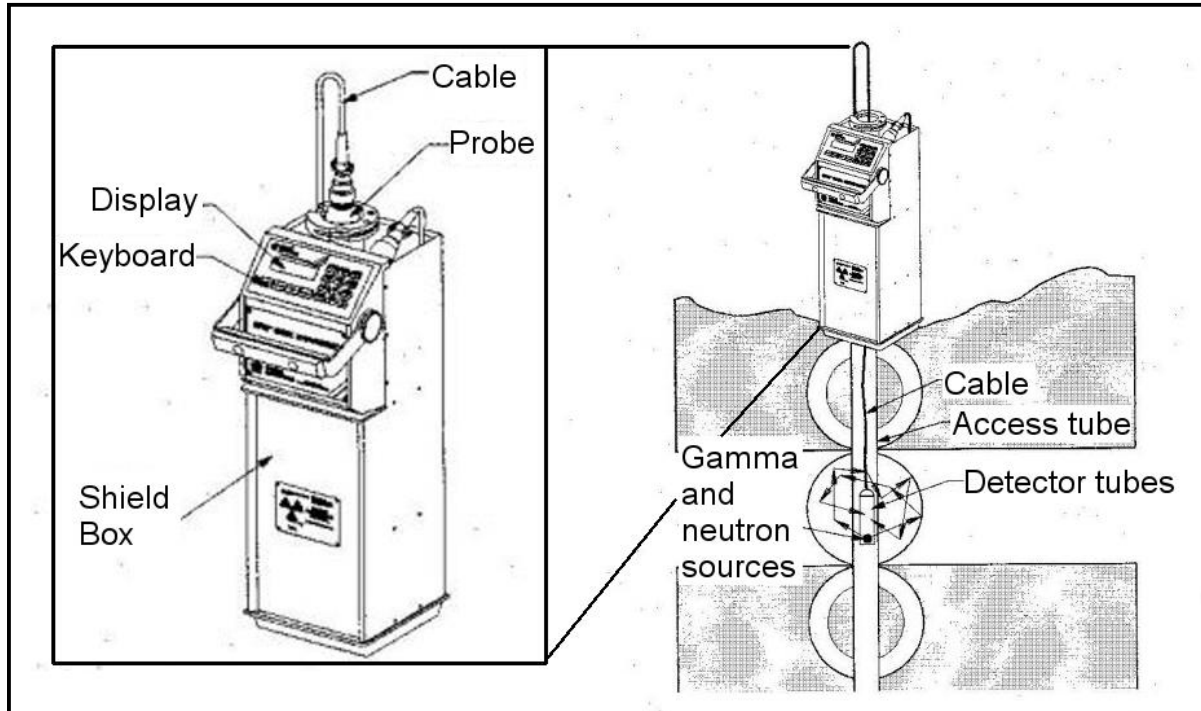


Figure 6: Schematic representation, adapted from CPN International Incorporated (1993), of the CPN 501DR Depthprobe. On the left, the different components of the control unit is shown. To the right, the control unit is shown where the probe is lowered in to the ground.

There are two types of neutron probes, the first is a probe that is lowered to the desired depth, by means of an access tube, at which the SMC needs to be measured (Schmugge *et al.*, 1980). The second type is a probe that measures only the top few centimetres of the soil (Schmugge *et al.*, 1980). Several nuclear sources can be used as a source of neutrons (Schmugge *et al.*, 1980). The preferred source, for SMC measurement, for these probes are Americium-241:Beryllium (as in the case of the CPN 501DR Depthprobe) (Bell & McCulloch, 1966; Chanasyk & Naeth, 1996; CPN International Incorporated, 1993; McKay & Acomb, 1996; Schmugge *et al.*, 1980). Older apparatuses made use of a Radium:Beryllium source to measure SMC (Schmugge *et al.*, 1980). Schmugge *et al.* (1980) states that a study found that the Americium-241:Beryllium source decreased the weight of the probe, increased the count rate, eliminated unwanted gamma radiation and could possibly increase depths and resolution which SMC can be measured. The Neutron probe measures the density of the soil by emitting

gamma radiation, with a Caesium-137 source (CPN International Incorporated, 1993; Lee, 2018; Strunk, 2009; Tokumoto, 2013). The gamma radiation that passes through the soil will then be detected by the Geiger-Mueller detector, which is located in the probe (CPN International Incorporated, 1993; Lee, 2018; Strunk, 2009; Tokumoto, 2013). If the same measurement time is used (e.g. 32 seconds), soils with high densities will give lower counts than soils with low densities – the reason being that a soil with a high density will absorb more gamma radiation (CPN International Incorporated, 1993; Lee, 2018; Strunk, 2009; Tokumoto, 2013).

To take subsurface measurements, a hole (the same size as the access tube or slightly smaller than the tube to ensure a tight fit) is drilled by an auger drill (Fayer & Gee, 2005; McKay & Acomb, 1996; Schmugge *et al.*, 1980; Smith & Mullins, 2001). The access tube is sealed with silicon and a plug at the bottom, as to ensure that moisture does not enter the tube (Schmugge *et al.*, 1980). The Neutron probe is then placed on a tripod (that is fitted with a tube that the control unit is placed upon) as shown in Figure 7. This tripod is placed above the installed access tube (that has been sawed off about five to ten centimetres above the soil), where the probe is then lowered into the access tube at predetermined intervals (in the case of this study- 20 centimetres). Figure 7 shows the control unit while a measurement was taken (the count ratio) and what the measurement was at that specific location. After the measurements were taken, the access tubes were sealed off by placing a plastic zip lock over the tube and fastening the bag with tape. This was done to ensure that no water enters the tube during an event of precipitation or irrigation.



Figure 7: To the left, the control unit showing that it is busy taking a measurement (count ratio). To the right, the measurement given by the control unit at a specific location.

For this study, PVC tubes were used, and this has been done successfully by many other studies that made use of the CPN 501DR Depthprobe (Biswas, 2014a; Biswas, 2014b; Biswas *et al.*, 2012; Biswas & Si, 2011; Fayer & Gee, 2005; Hu *et al.*, 2014). According to Schmugge *et al.* (1980), to ensure accurate measurements of SMC in soils, it is important that the Neutron probe is calibrated for each soil type. This will be done statistically, by means of calibrating the Neutron probe measurements with the volumetric measurements of each hole and depth. It was found that the in-field calibration of the CPN 501DR Depthprobe is very difficult and does not seem to work, and this is also the case in various other studies, as mentioned by Schmugge *et al.* (1980). For this reason, a laboratory calibration was done for this study. Schmugge *et al.* (1980) also states that to minimise drift, as mentioned above, it is important to take reference counts prior to each profile measurement.

2.5 DIVINER 2000 (DIVINER)

The use of frequency domain reflectometry (FDR) for indirect SMC measurement has been increasing over the last decade (Provenzano *et al.*, 2015). This is mainly due to these methods being easier and less destructive, as compared with traditional gravimetric water content methods (e.g. oven drying of samples) (Provenzano *et al.*, 2015). These FDR methods, though still destructive, are less destructive in the sense that only one hole has to be drilled at a specified location and an access tube can be inserted either temporarily or permanently. This access tube can then be used every time it is necessary for measurements to be taken. Where with traditional gravimetric- and volumetric methods, a new hole needs to be drilled every time samples are needed for analysis. The Diviner 2000 (produced by Sentek Propriety Limited) is a portable and lightweight SMC monitoring device and makes use of FDR (Charlesworth, 2000; Leatherdale *et al.*, 2012; Monti & Zatta, 2009).

The FDR method is used to measure the soils' dielectric constant, where the soil acts as a capacitor when it is placed between two electrical plates (Charlesworth, 2000; Paltineanu & Starr, 1997). By using this method the soil is included as part of the capacitor, where the permanent dipoles of H₂O (in this dielectric medium) become aligned and polarised by the electric field (Paltineanu & Starr, 1997). For the electric dipoles to influence the dielectric constant, the dipoles have to respond to the electric fields' frequency (Paltineanu & Starr, 1997). Local molecular binding forces mainly determine the freedom at which these electric dipoles respond, therefore the response of the dipoles is a function of the frequency (of the electric field) and the molecular inertia (binding forces) (Paltineanu & Starr, 1997). The dielectric constant is determined by the measurements of the capacitance, thus the SMC can be determined (Paltineanu & Starr, 1997). Apparatuses that use this method are therefore commonly referred to as capacitance probes (Charlesworth, 2000; Haberland *et al.*, 2015; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015; Silva *et al.*, 2007). Charlesworth (2000) furthermore states that a frequency (measured as voltage) is applied to the electric plates and the frequency measured in return varies as the soil dielectric varies.

The Diviner is a portable handheld SMC monitoring apparatus, that consists of a 1.6 metre probe rod with an automatic depth sensing apparatus (the probe cap and datum plate) and the sensor, where two electric rings are used to form the capacitor, all of which are connected to a display unit with a cable (Provenzano *et al.*, 2015). Figure 8 serves as a schematic representation of the Diviner 2000 and all the different components. The oscillator and the capacitor act as a circuit generator that generates an oscillating electrical field that is transmitted into the soil through the access tube (Paltineanu & Starr, 1997; Provenzano *et al.*, 2015). Paltineanu and Starr (1997) states that previous research has shown that operating at a frequency higher than 30 MHz greatly reduces the interference of fertilizers and soil water

salinity or acidity. According to Provenzano *et al.* (2015), the Diviner's circuit resonant frequency (or the raw counts) represents the output of the sensor, which is dependent on the surrounding soils' dielectric properties. These resonant frequencies can range from 240 MHz to 330 MHz, where saturated soil has a frequency of roughly 250 MHz and air dry soil has a frequency of roughly 287 MHz (Provenzano *et al.*, 2015).

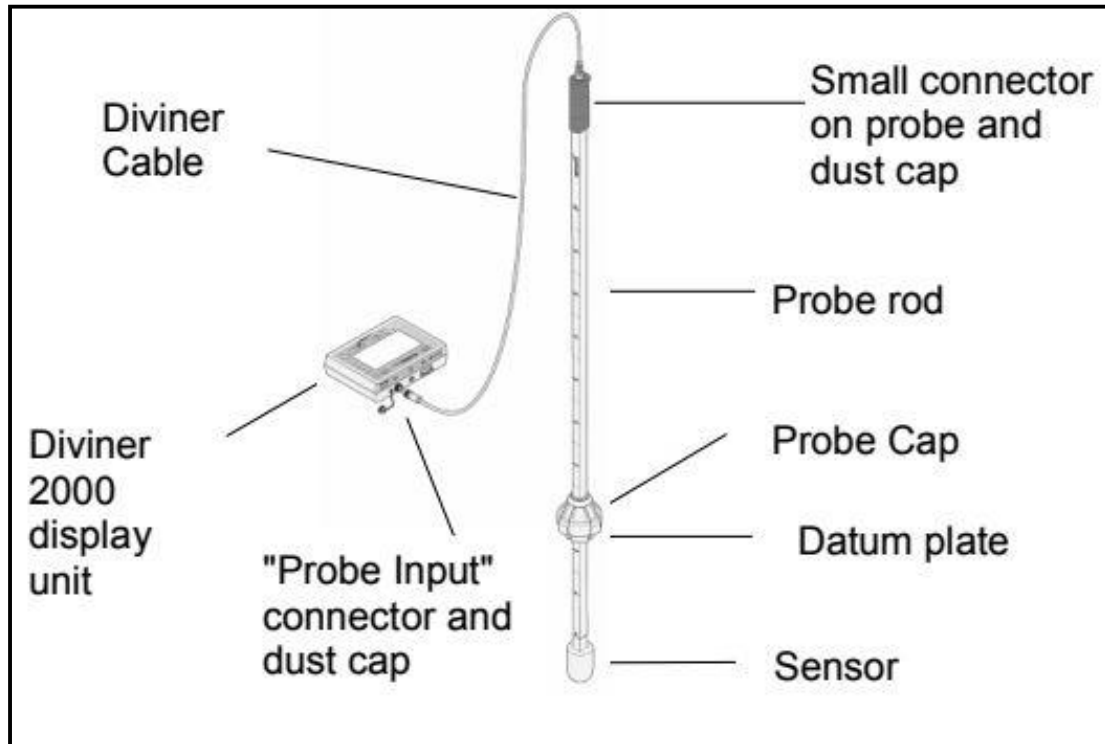


Figure 8: Schematic representation of the Diviner 2000, showing the probe and the display unit (Sentek Propriety Limited, 2009).

The frequency output of the sensor mainly varies with soil-water-air ratio variations, this is then measured by the Diviner (at the user specified locations) as the resonant frequency in the soil (F_s) (Paltineanu & Starr, 1997; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015). It is important to note that prior to soil measurements, the probe needs to be normalised for air- and water measurements (Paltineanu & Starr, 1997; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015). The air measurement (F_a) is taken by inserting the probe into the PVC access tube and holding the PVC tube still above ground while the data logging unit takes the air count (Haberland *et al.*, 2015; Paltineanu & Starr, 1997; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015; Sentek Propriety Limited, 2009; Silva *et al.*, 2007). The water measurement (F_w) is taken by placing the PVC access tube (with the probe) into a bucket of water (at least 10 litres), and holding the tube still at a minimum of 10 centimetres from the top, bottom and sides of the bucket as the data logging unit takes the water count (Haberland *et al.*, 2015; Paltineanu & Starr, 1997; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015; Sentek Propriety Limited, 2009; Silva *et al.*, 2007).

The F_s , F_a and F_w measurements are then used to determine the normalised count or scaled frequency (SF) by using a normalisation equation, which has an SF value between zero and one (Haberland *et al.*, 2015; Paltineanu & Starr, 1997; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015; Sentek Propriety Limited, 2009; Silva *et al.*, 2007). The normalisation equation used to determine SF is shown in Equation 3 (Haberland *et al.*, 2015; Paltineanu & Starr, 1997; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015; Sentek Propriety Limited, 2009; Silva *et al.*, 2007).

Equation 3: Formula to determine the scaled frequency for the Diviner 2000.

$$SF = \frac{(Fa - Fs)}{(Fa - Fw)}$$

To determine the volumetric soil water content (θ) with the Diviner, the standard calibration equation used is shown in Equation 4, where (specifically for the Diviner 2000) $A = 0.2746$, $B = 0.3314$ and $C = 0$ (Haberland *et al.*, 2015; Paraskevas *et al.*, 2012; Provenzano *et al.*, 2015; Sentek Propriety Limited, 2009). Due to this being the default calibration on the Diviner, the measurements were calibrated for volumetric measurements, which was done by a laboratory calibration protocol.

Equation 4: Calibration equation used to determine volumetric soil water content (θ) for the Diviner 2000.

$$SF = A \times (\theta^B) + C$$

It is important to note that the volumetric water content cannot always be determined with 100 percent accuracy, due to the effects of soil structure and texture, as well as other user errors (Provenzano *et al.*, 2015). Such user errors can be due to the incorrect installation of the PVC access tubes, where the auger used to drill the hole is too wide and the access tube is fitted too loose. This could cause errors in the data, because 99 percent of the sensors' response or sensitivity is within 10 centimetres of the PVC access tube wall, and the rest of the sensitivity extends to about 18 centimetres (Paltineanu & Starr, 1997; Provenzano *et al.*, 2015). This is important to take into consideration, as about half of the sensors' response is mainly depended on the SMC of the soil within one to two centimetres of the PVC access tube walls (Paltineanu & Starr, 1997; Provenzano *et al.*, 2015). This causes the Diviner to be very sensitive to air gaps formed by the incorrect installation of the PVC access tubes (Provenzano *et al.*, 2015).

2.6 THE GAP IN KNOWLEDGE

There is a gap in knowledge, especially in the industry, as to what method to use for consultation purposes. Uncertainties such as what apparatus is suitable at what scale; what method, technique or apparatus is most suited for different situations such as

precision farming, irrigation pivot management or dry land farming; what method, technique or apparatus should be recommended to farmers for constant long-term SMC measurement; what method, technique or apparatus is recommended as the best “all-round” solution for agronomists to consult farmers on irrigation; and finally what is the most accurate, but still the most cost- and labour efficient method of SMC measurement. Although, as of yet, there are no miracle apparatuses available that offers an all-in-one solution with perfect accuracy, low cost and minimal labour, there are apparatuses that have one or more of these functions. Methods that are very precise and accurate tend to be very expensive, apparatuses that are cheaper tends to lose on the accuracy end of the spectrum and methods that offer precise results with little to no labour tends to be extremely expensive (so much so that it becomes questionable if these methods are worth using at all).

To answer these questions, researches have been researching individual methods and apparatuses to try and discover the perfect way to use it with minimal effort, but maximal results. Other researchers have studied and compared different methods and apparatuses, to try and find the perfect middle ground where one apparatus or method makes up for the others’ shortcomings. At this point in time, the best answer is probably to firstly, do a very detailed study of the area in question to build up a complete database and to determine factors such as salinity, possible pollution and soil quality to use one apparatus where all factors and variables can be measured, calculated and calibrated. Secondly, two or more methods could be used in conjunction to achieve the best possible results.

The methods and apparatuses used in this study have all been well researched. There are studies where FDR, Neutron scattering, EM, gravimetric and volumetric methods have been used in conjunction in one arrangement or another (e.g. FDR with Neutron scattering, EM with neutron scattering, FDR and EM), but there are very little, to no studies where these specific methods and apparatuses have all been studied together and compared. As part of the aims, this study will compare these methods and answer some of the mentioned questions.

Examples of studies done on FDR or the Diviner 2000 alone are such as Groves and Rose (2004); Haberland *et al.* (2015); Provenzano *et al.* (2015); Tedeschi *et al.* (2014). Examples of studies done on the Diviner 2000 and TDR are Evett *et al.* (2006); Gebregiorgis and Savage (2006). Examples of studies combining neutron scattering,

FDR and TDR are Evett *et al.* (2002a); Evett *et al.* (2002b); Heng *et al.* (2002). Finally, some examples of studies including EM methods and FDR are Coppola *et al.* (2019); Rallo and Provenzano (2017); Rallo *et al.* (2018); Utili *et al.* (2014).

CHAPTER 3: MATERIALS AND METHODS

3.1 INTRODUCTION

Firstly, this chapter focuses on the site specifications. Secondly, the methodology of the study will be described in detail, which includes the procedures followed for sampling and sample analysis. Thirdly, the monitoring and assessment protocols will be discussed. Lastly, the methods and software used for data analysis will be discussed.

3.2 STUDY AREA

The study area (marked with a yellow border in Figure 9) is located on a farm, Cyferfontein farm, which is situated roughly 50 kilometres Southwest of Potchefstroom. The area of study is located in the Free State Province and borders the Vaal River, which forms the provincial border between the Free State Province and the North West Province. This study focused specifically on the number four pivot (shown with a red border in Figure 9), which covers an area of approximately 56 hectares. This farm produces a large range of mix crops, some of which includes *Arachis hypogaea* (peanuts), *Phaseolus vulgaris* (green beans), *Vigna unguiculata* (cowpeas), *Zea mays* (maize), *Triticum* (wheat) and *Citrullus lanatus* (watermelons).

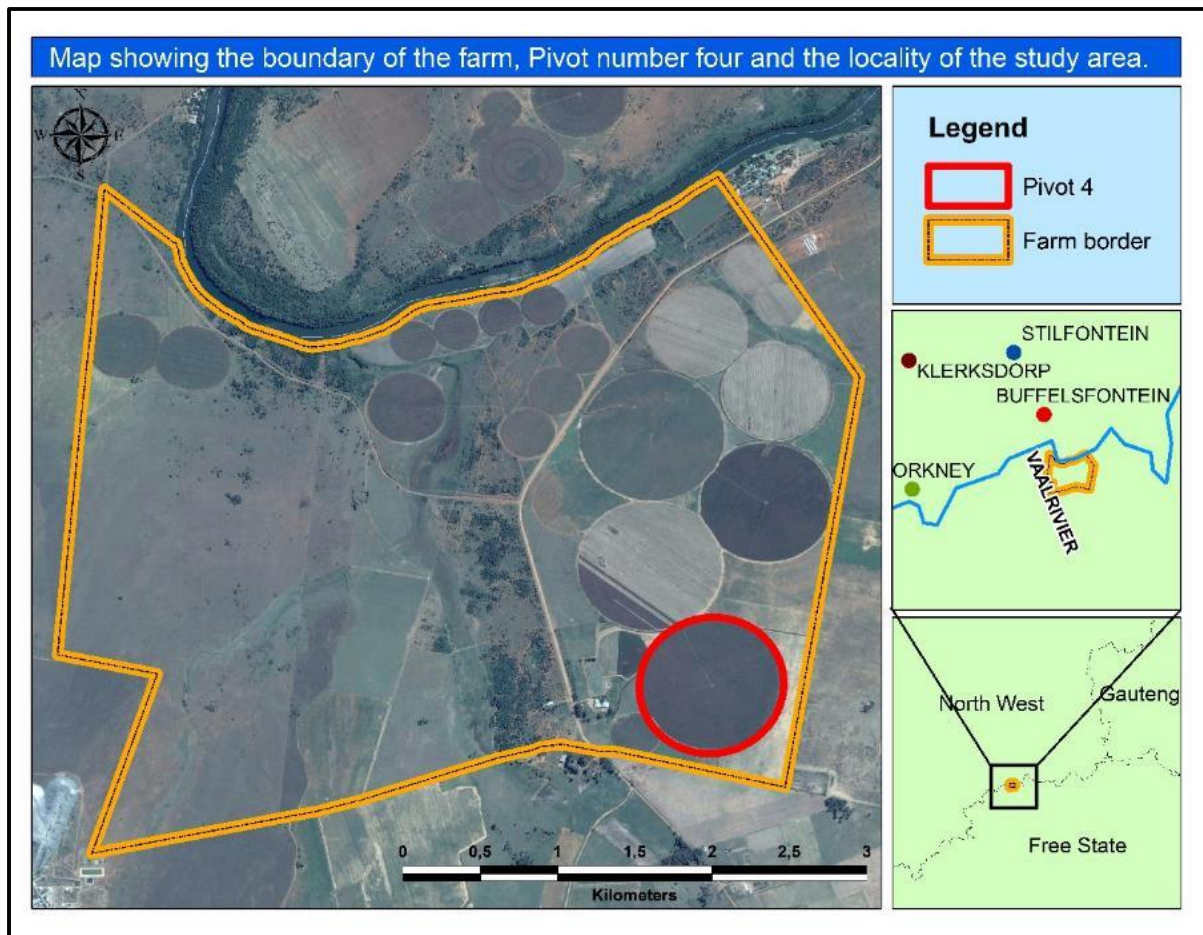


Figure 9: Locality map of Cyferfontein farm (in yellow), the specific pivot under investigation (in red) and locality of the study area (which falls in the Free State Province) (Google Earth, 2016a).

3.2.1 Climate

The regional climate of the area of study is that of a typical South African Highveld, having low rainfall and warm to hot temperatures in the summer, with sunny, dry and cold winters (Meteoblue, 2018; Spangenberg, 2000). The average maximum summer temperature is 29 °C, and the average minimum is roughly 14 °C (in Figure 10) (Meteoblue, 2018; Spangenberg, 2000). The average maximum winter temperature is 21 °C, and the average minimum is 3 °C (in Figure 10) (Meteoblue, 2018; Spangenberg, 2000). The average yearly regional rainfall of this study area is roughly 490 millimetres (of which the winter rainfall is about 100 millimetres and the summer rainfall 390 millimetres) (Meteoblue, 2018; Spangenberg, 2000). According to Odendaal (1991) and Spangenberg (2000), this is just more than half of the world's yearly average rainfall of roughly 860 millimetres, and this makes water in this area a very limited resource.

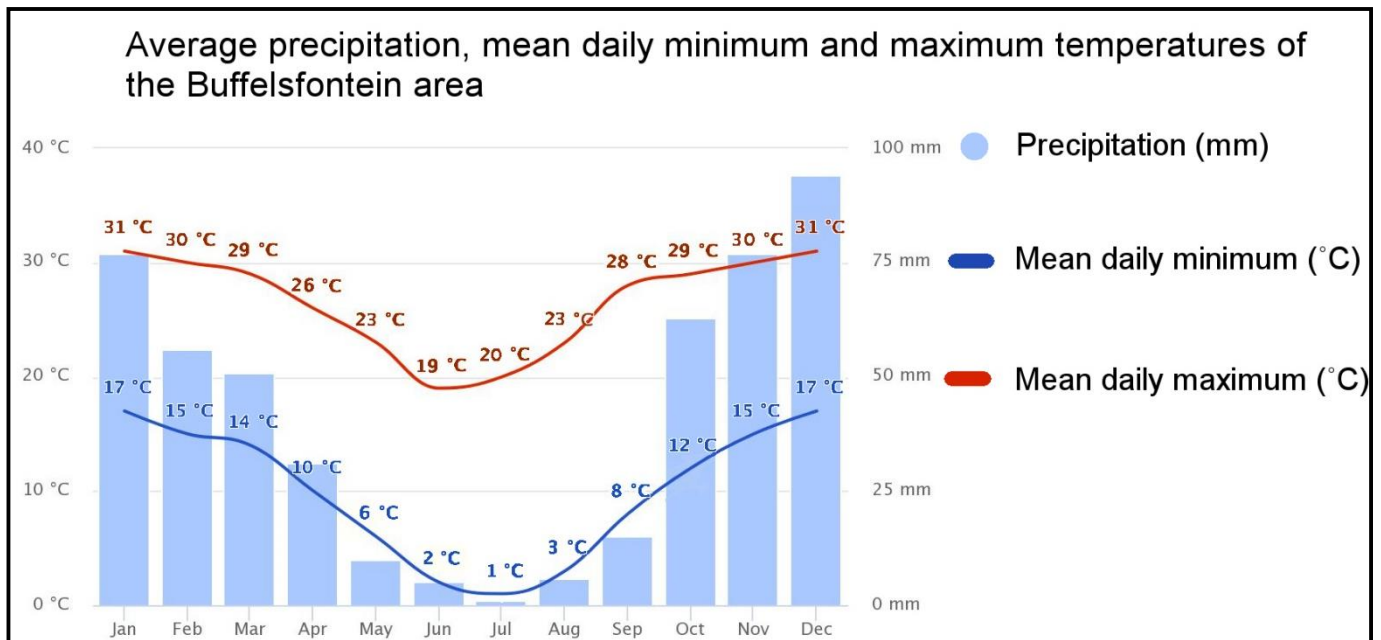


Figure 10: Graph showing the average precipitation (mm), mean daily minimum temperatures (°C) and the mean daily maximum temperatures (°C) for the Buffelsfontein area.

3.2.2 Soil

Figure 11 shows the soil map, which was done for Pivot four on the Cyferfontein farm. The map shows the occurrence of, mainly, five soil forms. These soil forms include:

- I. Avalon form (orthic A on a yellow-brown apedal B on a soft plinthic B) (Soil Classification Working Group, 1991).
- II. Constantia form (orthic A on an E horizon on a yellow-brown apedal B) (Soil Classification Working Group, 1991).
- III. Longlands form (orthic A on an E horizon on a soft plinthic B) (Soil Classification Working Group, 1991).
- IV. Wasbank form (orthic A on an E horizon on a hard plinthic B) (Soil Classification Working Group, 1991).
- V. Westleigh form (orthic A on a soft plinthic B) (Soil Classification Working Group, 1991).

The Longlands soil form occupies the largest surface area (25.91 ha), followed by Wasbank (21.59 ha), Avalon (4.75 ha), Westleigh (2.03 ha) and finally Constantia (1.81 ha).

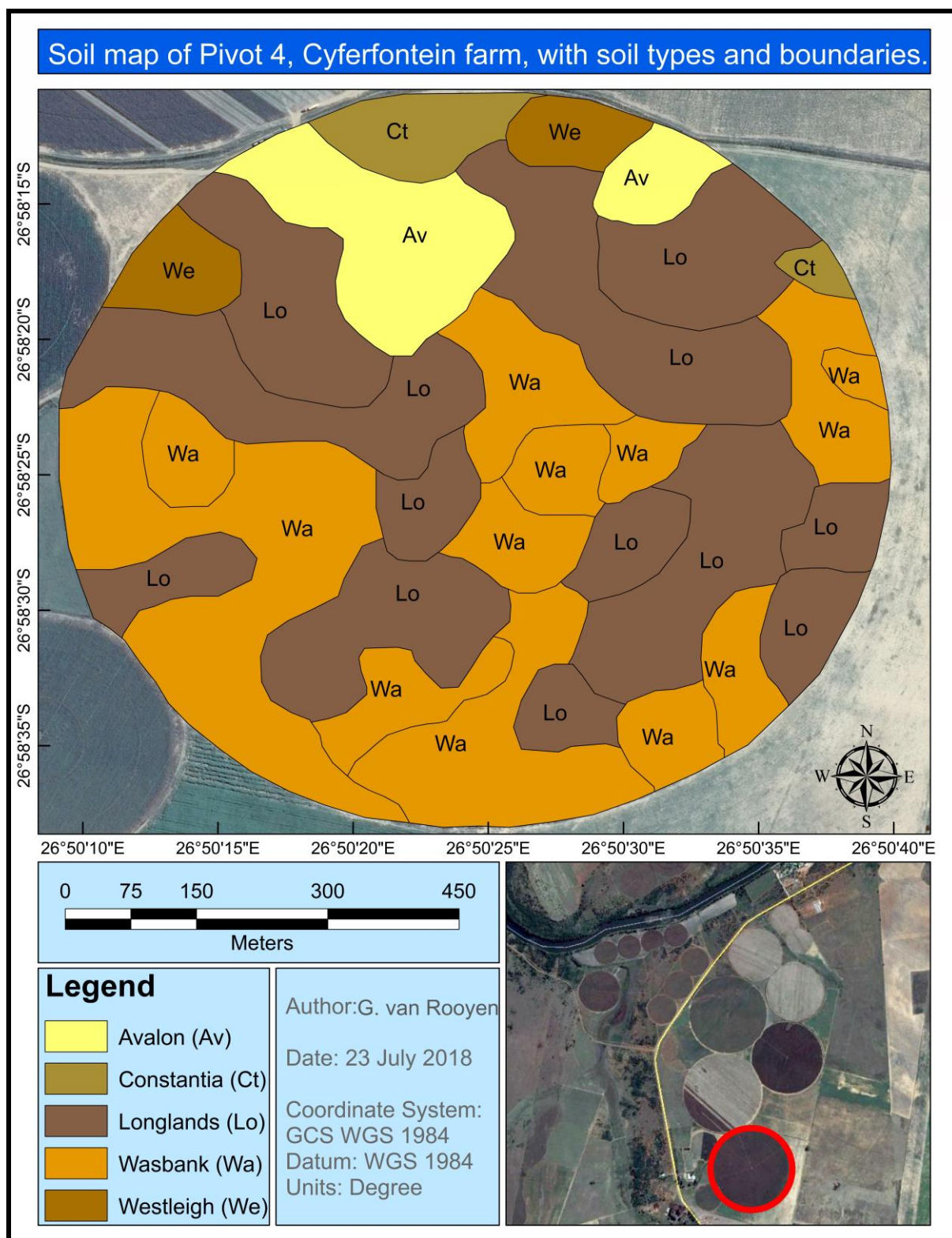


Figure 11: Soil map of Pivot four, Cyferfontein, showing the occurrence of Avalon, Constantia, Longlands, Wasbank and Westleigh soil forms (Google Earth, 2016a; Google Earth, 2016b). The map was created by G. van Rooyen (Omnia), and was edited by the author.

3.2.3 Geology

The study area is mainly underlain by two geological Supergroups, firstly the Transvaal Supergroup and secondly, the Karoo Supergroup (Johnson *et al.*, 2006). The Transvaal

Supergroup, which forms part of the late Archean to the early Proterozoic, is present in three different structural basins (Johnson *et al.*, 2006). The three basins include the Transvaal Basin, the Griqualand West Basin (both of which located in Southern Africa) and the Kanye Basin (located in Botswana) (Johnson *et al.*, 2006). According to Johnson *et al.* (2006), the Griqualand West Basin can be subdivided into the Prieska- and the Ghaap Plateau sub-basins. The succession that is preserved in the three different structural basins are overall very similar, correlating the best in the lower chemical sedimentary units and worst in the upper volcanic and upper clastic sedimentary lithologies (Johnson *et al.*, 2006). The Southwest part of the Griqualand West Basin has undergone extensive deformation with up to seven phases dating between more than 2500 million years and 1100 million years ago (Johnson *et al.*, 2006).

The Bushveld Complex intruded the Transvaal Basin approximately 2060 million years ago, resulting in the Magaliesberg Formation (forming part of the Pretoria Group) (Johnson *et al.*, 2006). This is of particular interest to this study, as the Pretoria Group forms the main geological unit found in the Northwestern part of the study area. The Pretoria Group is generally six to seven kilometres thick and predominantly consists of mudstone, quartzitic sandstones, interbedded andesitic lavas, diamictites, conglomerates and carbonate rocks (Johnson *et al.*, 2006). According to Johnson *et al.* (2006), all of the predominant rocks mentioned have all undergone low-grade metamorphism. The Northwestern part of the study area, which is underlain with the Pretoria Group, consists mainly of mafic- to ultramafic volcanic rocks.

The Karoo Supergroup is internationally known for its distinctive plant assemblages, thick glacial deposits and glacial pavements, extensive flood basalts with associated dolerite sills and dikes, and terrestrial vertebrate fossils (Johnson *et al.*, 2006). The Karoo Supergroup forms part of the Late Carboniferous to Middle Jurassic and has an approximate cumulative thickness of around 12 kilometres (Johnson *et al.*, 2006). The majority of the Karoo strata is found in the main basin and covers an approximate area of 700 000 square kilometres (Johnson *et al.*, 2006). Johnson *et al.* (2006) states that the Main Karoo Basin is predominantly underlain by a stable floor, consisting of the Namaqua-Natal Metamorphic Belt (to the South) and the Kaapvaal Craton (to the North). After the deformation of the Namibian Saldania Belt (Neoproterozoic) and the intrusion of the Cape Granite Suite (around 500 to 560 million years ago), the deposition of the Cape Supergroup sediments (Ordovician to the Early Carboniferous) took place (Johnson *et al.*, 2006). The Cape Supergroup is comprised of an eight kilometre thick passive margin clastic wedge, and consists of sandstones and mudstones that is derived from a Northern cratonic provenance (Johnson *et al.*, 2006). To the East of the basin, Natal Group sandstones accumulated in an elongated downwarp. After this, inversion

took place in the basin, where source areas found in the South of the basin contributed to the Karoo sediments (Johnson *et al.*, 2006).

The Eastern and Southern parts of the study area is underlain by the Madzaringwe Formation, forming part of the Karoo Supergroup (Johnson *et al.*, 2006). This formation generally consists of ≤ 200 metres of alternating shale, sandstone and siltstone, of which thin coal seams can be present in the shale (Johnson *et al.*, 2006). The feldspathic sandstones are commonly cross-bedded and very often these sandstones are micaceous (Johnson *et al.*, 2006). The basal 25 to 35 metres of the Madzaringwe Formation consists of carbonaceous shale, often containing thin coal seams. The main coal seam (two to three metres thick) was developed roughly 85 to 100 metres above this carbonaceous zone (Johnson *et al.*, 2006). According to Johnson *et al.* (2006), an enormous, 10 to 15 metre thick, micaceous, coarse-grained feldspathic sandstone layer caps the Madzaringwe Formation. It is hypothesised that this formation was deposited by meandering rivers, generally flowing from the Northwest (Johnson *et al.*, 2006). According to Johnson *et al.* (2006), these sandstones represent levee, crevasse-splay and point-bar deposits (see Figure 12). Lastly, the coal seams found in this formation were formed due to the accumulation of plant material in the flood basins under cool- and reducing conditions (Johnson *et al.*, 2006).

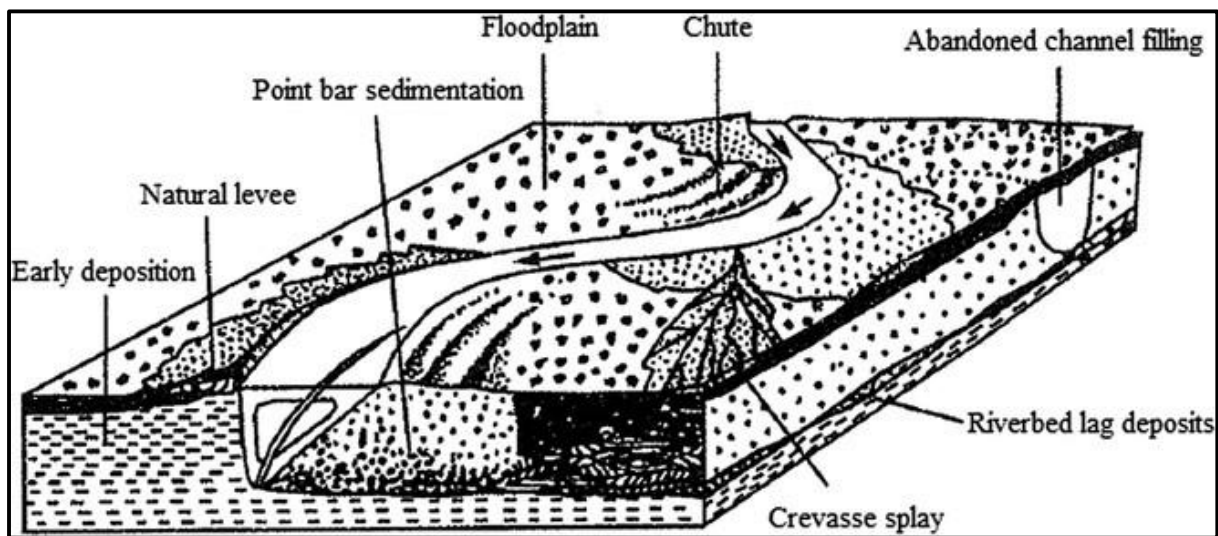


Figure 12: Schematic representation of a meandering river and the sedimentary model thereof, after Allen (1964) and Yu *et al.* (2018).

3.3 METHODS

3.3.1 Grid systems

For the CMD Explorer, a 20 by 20 metre grid was established by the use of GPS coordinates (using the WGS 1984 datum) as shown in Figure 13. This grid was setup by configuring the end and start coordinates of each traverse. In the field, flags were planted at the start and end of each traverse, to make it easier to stay on the grid.

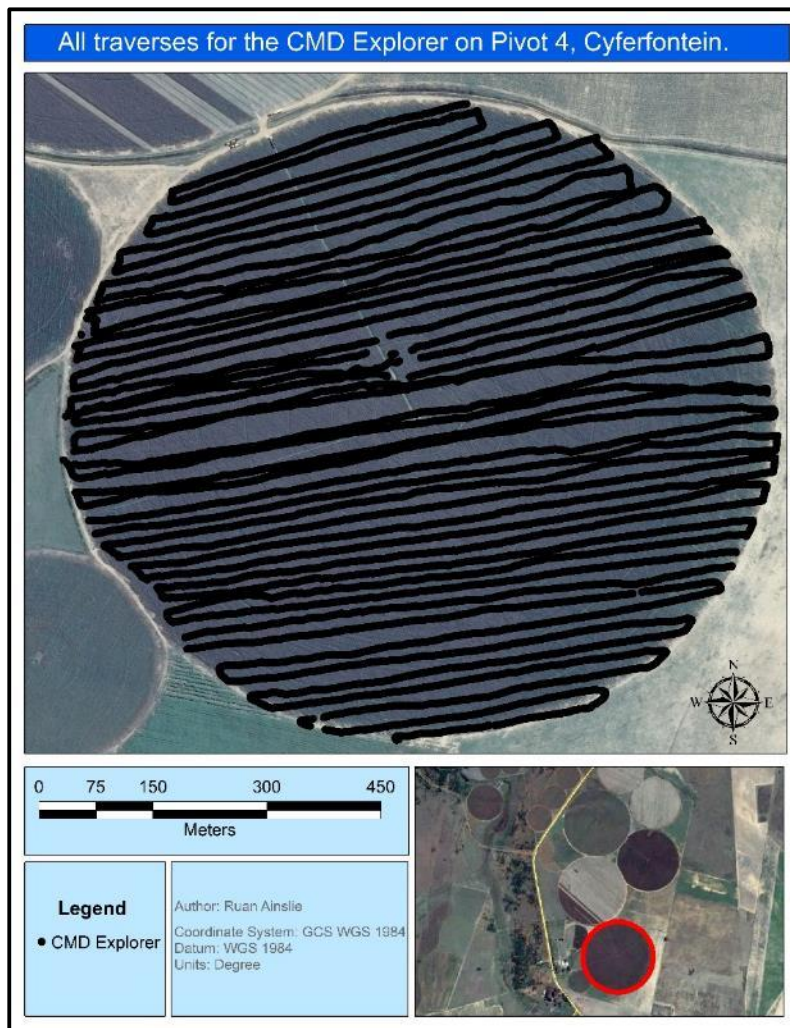


Figure 13: All traverses walked with the CMD Explorer, which was done on a 20 by 20 metre grid, on Pivot four (Google Earth, 2016a; Google Earth, 2016b).

A 10 by 10 metre grid was used for the CMD Mini-Explorer, which is shown in Figure 14. No predetermined grid was used for the collecting of the CMD Mini-Explorer data. The reason being that the CMD Mini-Explorer was towed behind an ATV. The CMD Mini-Explorer was towed at a distance where the ATV would not affect the measurements (the distance was determined before the data collection started). The reason for this grid being very random was due to the difficult terrain encountered, as the data was collected three months after harvesting of the wheat that was planted the previous planting season. The implements used caused deep trenches in the field, and the ATV could not drive through these trenches. Another reason being that the field was harvested in no particular orientation (e.g. North to South), leading to difficulties operating the ATV and keeping an accurate sense of direction.

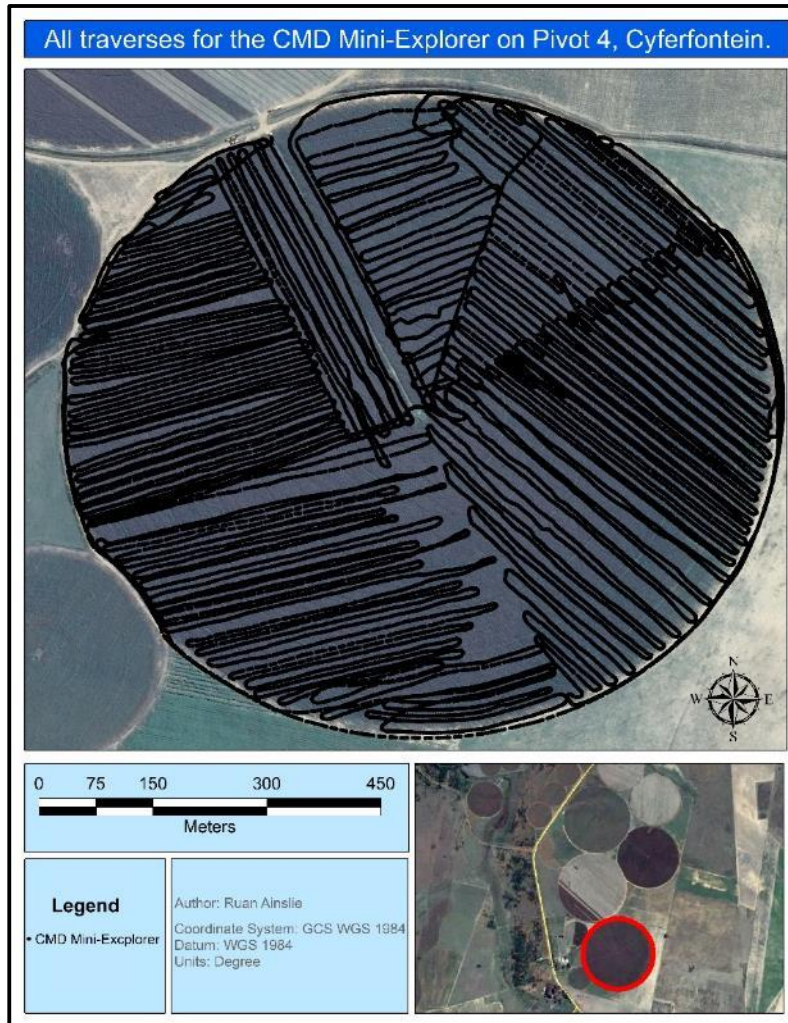


Figure 14: All traverses travelled with the CMD Mini-Explorer, which was done roughly on a 10 by 10 metre grid, on Pivot four (Google Earth, 2016a; Google Earth, 2016b).

For the collection of the Neutron probe-, Diviner 2000- and gravimetric data (implying that the soil samples were taken by means of auger drilling), a predetermined grid of 100 by 100 metres were used and was represented in Figure 15. It was at these marked locations where the holes were drilled, and the access tubes installed. The reason for profile 5.7 and 5.8 (in Figure 15) being skew and not exactly in line with the traverse five, was due to the field fire encountered. After the field fire, the field was ploughed and sugar beans were planted. This lead to unfavourable conditions while carrying and moving the equipment.

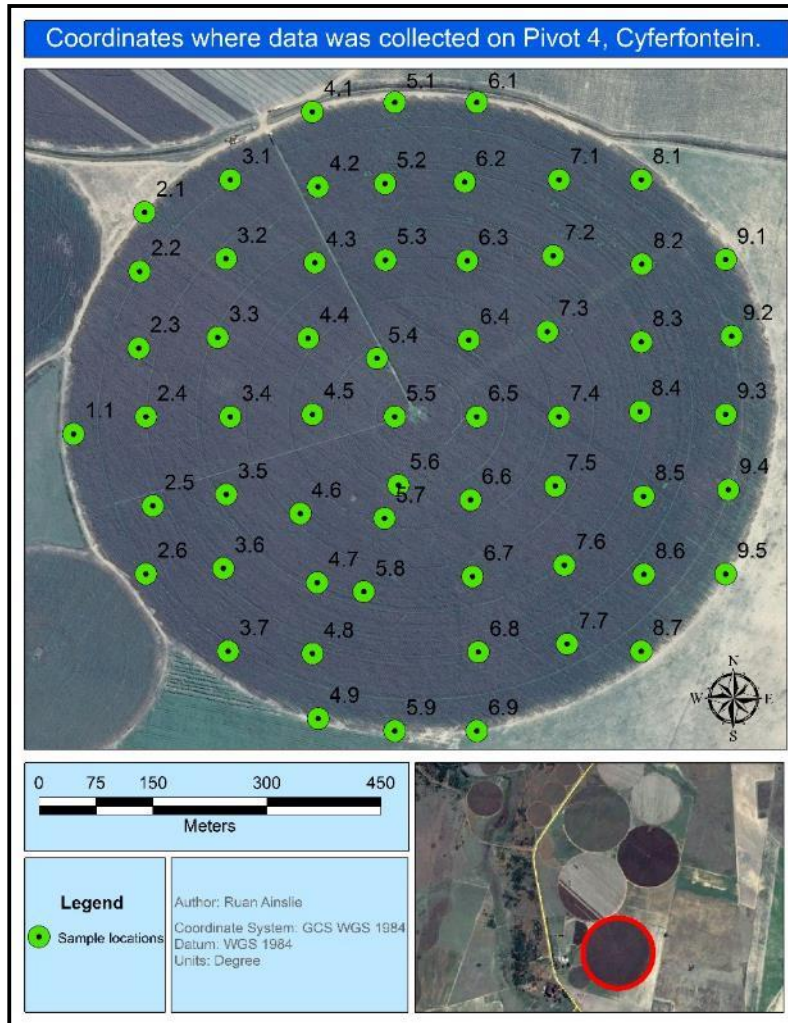


Figure 15: The coordinates used (based on a 100 by 100 metre grid) for the collecting of the Neutron probe data, Diviner 2000 data and soil samples (Google Earth, 2016a; Google Earth, 2016b).

3.3.2 CMD

3.3.2.1 Setup and operation

The setup for the CMD Mini-Explorer and CMD Explorer are very similar, seen as both of these apparatuses are based on the same principle and have the same control unit (note that each apparatus had its own control unit) (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Simon *et al.*, 2015). Firstly, the orange tubes (containing the transmitter and receiver coils) were connected to each other by tightly screwing these tubes together (where the CMD Mini-Explorer consists of two tubes and the CMD Explorer of four). The control unit, in the case of the CMD Explorer, was then connected to the tubes by means of a cable connection, and fastened to the tubes with a clamp that was screwed on. During this step, it is important to connect the control unit in the correct position, as the orientation (or rotation) of the tubes determine whether it is in the HCP or VCP position (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Shanahan *et al.*, 2015). Thereafter the tubes, with the control unit, were connected to a harness, which was then placed on the shoulders of the person operating the apparatus. In the case of the CMD Mini-

Explorer being used on foot, the tubes are connected to the bottom of the arm holster, and thereafter the control unit is fastened to the arm holster with a clamp. In the case of the apparatus being towed behind an ATV, the tubes were securely fastened to the sleigh, which was attached behind the ATV. In both cases, the control units are connected to the tubes (containing the transmitter and receiver coils) by means of a Bluetooth connection (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Simon *et al.*, 2015). The final step, with both the Explorer and Mini-Explorer, were to connect a GPS device to the control unit, by means of a cable connection or a Bluetooth connection (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015). The average set up times, as mentioned in Chapter 2, was about 10 - 15 minutes for the CMD Explorer, and less than 20 minutes for the CMD Mini-Explorer (if towed behind an ATV) (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015).

For the CMD, no calibration protocol is required, seen as the apparatus automatically compensates for changes in temperature (Bonsall *et al.*, 2013; Jadoon *et al.*, 2015; Simon *et al.*, 2015). Therefore, after the setup, one can immediately start collecting data by walking the predetermined grid. It is important to note that all required settings, for the specific investigation, were pre-loaded. These setting include, firstly, the time intervals at which the apparatus takes readings – for the CMD Explorer, this was set at one second intervals, and for the CMD Mini-Explorer it was set as 0.5 second intervals. The reason for the different time intervals of the two apparatuses was due to the difference in speed at which the apparatuses operated, where the CMD Explorer was used on foot and distances were travelled much slower than those travelled by the ATV towing the CMD Mini-Explorer. Furthermore, the ‘*continuous measurement*’ setting was used for both these apparatuses, which just means that measurements are taken continuously and automatically (according to the time interval set), where if the ‘*manual measurements*’ setting was active, one would need to take manual readings at set points (which is simply done by pressing a button that is conveniently located on both apparatuses).

After the setup, the CMD Explorer was used by walking the grid, as discussed above, and the CMD Mini-Explorer was towed by an ATV according to the grid discussed above. To save time, the CMD Mini-Explorer and Explorer was used simultaneously. However, it is noteworthy to mention that the measurements taken by each apparatus could influence each other at close proximity. The influence parameter was tested and determined in the field prior to the collection of data. This was done by taking measurements on both apparatuses starting at a very close proximity and moving them further away from each other until it was clear that the measurements taken were not affected by the other apparatus. During the data collection, care was taken as not to bring the apparatuses too close to each other. Further care was taken to not take measurements too close to the vehicle used in the field, as this could greatly influence measurements and lead to errors in the data. During the field visits, the irrigation

pivot was encountered (which also influences the measurements) by the CMD Explorer, but during the whole period that the data was collected, the pivot was stationary. This makes it easier to delineate the anomalies from the errors (or false readings) caused by the pivot.

3.3.2.2 Data analysis

All measurements taken by the CMD Mini-Explorer and CMD Explorer are automatically stored on the control unit of each apparatus. The stored data was then downloaded onto a Universal Serial Bus (USB) flash drive, which was done with the control unit and no external software were needed for the downloading of the data. This data was then exported onto a computer by using the *CMD Data Transfer* software (made available by GF Instruments, and is freely accessible at http://www.gfinstruments.cz/index.php?menu=gi&smenu=iem&cont=cmd_&ear=dl). This software converts the data into a useable format, which is compatible with *Microsoft Excel*.

The data was then imported into *Microsoft Excel* and processed. In this dataset, the coordinates and apparent conductivity measurements of each apparatus (for all three depths, as discussed in Chapter 2) were sorted and put into tables to facilitate the data processing. After this, the data was firstly imported into *Surfer 11*, where grid files were created for each depth measured (specifically the apparent conductivity of each depth measured) by means of Kriging. By using these grid files, contour maps were created for each depth of measurement, and a specified, universal colour scheme was given for each map. In this first step, it is possible to identify errors or false readings (such as the irrigation pivot encountered).

In the case where errors were present, the raw datasets were then loaded into *ArcGIS – ArcMap 10.3* – to identify and delineate errors. Therefore, the second step of processing the data included creating a shapefile, in which the attribute data can be accessed. After this, the data was displayed on a georeferenced image of Pivot four (based on the WGS 1984 coordinate system). The symbology was categorised to present the data as lowest to highest apparent conductivity measurements. This made the process of identifying errors (i.e. the pivot that was encountered) more accurate and efficient. The points of concern were then selected, and a new layer was created for all the selected points. The errors (or outliers in the data) was easy to distinguish from the data, as the apparent conductivity measured under the pivot was extremely high compared to the measurements of the rest of the field. This layers' attribute data was then exported to be used in *Microsoft Excel*. This dataset was then used to delineate all errors present in the first dataset. Due to the measurements being taken very close to each other, removing the outlier data did not create gaps or distorted results. After the original dataset was processed and cleaned, the first step was repeated and all maps were created to visually represent the data. Note that the datasets for the CMD Mini-Explorer and Explorer

was too large to add to the appendices, therefor (if necessary) the datasets can be sent via e-mail if required.

3.3.3 Gravimetric and volumetric measurements

3.3.3.1 Setup and operation

For the gravimetric-, volumetric-, Neutron probe- and Diviner 2000 data, the same grid was used (refer to Figure 15). Based on the 100 by 100 metre grid, holes were drilled by an auger drill as deep as possible or until resistance was encountered (in this case it was a pebble layer). The auger drills used, was capable of drilling up to a depth of 2.1 metres. The diameter of the augers used, was approximately seven centimetres, as this was the width of the access tubes that had to be installed. As the auger filled up, it was removed from the soil and emptied into plastic zip sealed bags. These samples were then bagged and tagged (and sealed by the use of masking tape) for further analysis at the lab. The samples were put in a 25 litre plastic bucket, which could be sealed shut, as to minimise moisture loss during fieldwork. Furthermore, these samples were then put in the vehicle, out of direct sunlight, also to minimise possible moisture gain or -loss. After the holes were drilled, the PVC access tubes were installed and cut off between five and ten centimetres above ground level. This was done to ensure that both apparatuses used (the Neutron probe and the Diviner 2000) could be operated correctly. The PVC pipes were also prepped beforehand, where each tube had a plug inserted at the bottom and sealed off with silicon, to ensure that no moisture would enter the pipe after being installed. After all measurements were taken, the tubes were temporarily sealed off, by means of securely taping a thicker plastic bag around the tube's top. This was done to ensure that water or moisture would not enter the tubes during periods of precipitation or irrigation.

For the analysis of the gravimetric and volumetric water contents, the standard ASTM D2216 procedure was used, although the standard procedure was modified (ASTM, 2010). At the lab, the bags containing the soil samples were emptied into steel containers. Note that for accuracy purposes, all samples were processed within 24 hours of collection, as to ensure that there was no moisture loss or -gain. Each container was then weighed in the wet condition and numbered. These weights were then recorder by hand to be used later on. After this, the samples were put in industrial ovens at 105°C for 24 hours (Bell *et al.*, 1987; Hillel, 2003; Smith & Mullins, 2001). After the drying process, the samples were weighed again, this time in the dry condition. These dry weights were then also recorded by hand.

3.3.3.2 Data analysis

The complete dataset, which included the wet- and dry weights (See Appendix 2 for the gravimetric dataset and Appendix 3 for the volumetric dataset), was imported into *Microsoft Excel*. Firstly, the gravimetric water contents (V_W) were calculated by using Equation 5.

Equation 5: Formula to determine the gravimetric water content (Hillel, 2003; Smith & Mullins, 2001).

$$V_W = M_W / M_S = (Wet - Dry) / Dry$$

Where the mass of water lost due to drying (M_W) was divided by the dry mass (M_S). M_W was calculated by subtracting the wet mass from the dry mass, and dividing this value with the dry mass. Secondly, the volumetric water content (θ) in this dataset was calculated by using Equation 6.

Equation 6: Formula used to calculate the volumetric water content, derived from Hillel (2003), Kodikara et al. (2013) and Smith and Mullin (2001).

$$\theta = V_W \cdot \rho_b$$

Where V_W was simply multiplied by the Dry bulk density (ρ_b) to calculate θ . The ρ_b was calculated using the calibration protocol designed for the Neutron probe (which is discussed in detail in section 3.3.4.3 of this chapter).

3.3.4 Neutron probe

3.3.4.1 Setup and operation

The Neutron probe had no prior- or in-field calibrations to be done for fieldwork, seen as the calibrations were done in the laboratory (Tokumoto *et al.*, 2012). The Neutron probe works by lowering the probe (which is attached to a cable with clips at 20-centimetre intervals) into the soil, and measurements were taken manually (Biswas, 2014a; Biswas, 2014b; Hu & Si, 2014; Silvestri, 1999; Tokumoto *et al.*, 2012). After the hole had been drilled for the gravimetric samples, a PVC access tube was installed into the drilled hole (Biswas, 2014a; Biswas, 2014b; Hu *et al.*, 2014; Silvestri, 1999; Tokumoto *et al.*, 2012). The access tubes were pushed into the holes, and hit with a rubber mallet to secure a tight fit (Silvestri, 1999). The part of the tube that was above ground was sawed off at approximately five centimetres to allow access for the Neutron probe (which was placed on a tripod stand, as shown in Figure 16) and the Diviner 2000's probe. Prior to each profile reading, a standard measurement was taken with the Neutron probe, while the probe was still in the protective casing of the apparatus. Thereafter, a measurement was taken manually at every clip interval (of 20 centimetres), for the entire depth of the hole (Biswas, 2014a; Biswas, 2014b; Hu & Si, 2014; Tokumoto *et al.*, 2012). These measurements are given on the display unit on the apparatus, and were recorded manually by hand. Each profile was given a name (e.g. 1.1, 2.2, 2.3, etc.). At the end of each

fieldwork session, the data was imported into *Microsoft Excel* and processed later. The measurements for soil moisture content were taken at 16 second intervals at each clip, as this is efficient for soil moisture measurements (CPN International Incorporated, 1993; Silvestri, 1999).



Figure 16: To the left, the Neutron probe is shown where it was placed on top of the tripod stand. To the right, the Neutron probe is placed in the protective carrycase.

For the density measurements, the same process was followed, accept the apparatus was set to measure dry density (this was done to ensure accuracy, where each density measurement was set to be measured for the dry density). The density measurements, for this specific study, were taken at 32 second intervals for each 20 centimetre clip interval. Silvestri (1999) and CPN International Incorporated (1993) states that 64 second intervals are the preferred time interval, with optimal accuracy in mind. The reason for the longer time period set for the measurement of density, as opposed to the measurements of SMC, is so that a higher degree of accuracy can be acquired. The degree of accuracy increases, as the time period for each measurement increases (this includes both SMC and density). However, the timeframe and

the quality of work should be taken into consideration, as it is not realistic to take 64 seconds, or higher, measurements on a 56-hectare study area. Therefore, the time for each measurement was made shorter, but more care was taken to ensure that calibration measurements were taken at each profile.

3.3.4.2 *Density calibration protocol*

For the density measurements taken by the Neutron probe (for all the raw data see Appendix 1), a calibration protocol was set up to calibrate the absolute density measurements (as the density measurements taken by the Neutron probe were relative density measurements) (Kodikara *et al.*, 2013; Smith & Mullins, 2001). This was done by taking three identical 55 litre plastic drums and filling one with water, one with loose uncompacted soil ($1.19\rho_s$), and the last one was filled with soil and was then compacted to $1.76\rho_s$. Prior to filling the drums, the same PVC access tubes used in the field were installed precisely in the centre of the drum. The tube was installed to the bottom of the drums by using industrial grade epoxy (specifically designed for PVC and other plastics). This was done to ensure that all readings were taken at the same distance from the walls of the drum, as the readings would not be as precise if the tubes shifted during the filling process of the water and soils into the drums.

For the first drum (which was filled with water), smaller buckets were used to fill the drum with precisely 55 litres of water. This was done by firstly measuring off five litres of water into a bucket, which was achieved by measuring the precise level of five litres of water in the bucket, by using a one litre volumetric flask. The water level was then marked in the bucket, which was then used to fill a 20 litre bucket with water. Where four five litre buckets were emptied into the larger bucket, and this water level was then marked. By using this method, the larger drum was filled with precisely 55 litres of water. A temporary plug was installed at the top of the tube, to ensure that no water would enter the tube during the filling process.

For the second drum, a large amount of Hutton soil (this soil formation consists of an orthic A-horizon on a red apedal B-Horizon, and is classified as a luvisol B1 horizon – 2200, Suurbekom) was dried for five days (Soil Classification Working Group, 1991). This dry soil was then used to fill up the second drum to the exact same mark as the first drum, to ensure that the same volume of soil was used for this part of the protocol. Care was taken to add the soil carefully and slowly to minimise compaction. A temporary plug was also installed during this process, to ensure that no soil entered the tube.

The third and final drum was firstly marked off at 10 centimetre intervals using a one metre ruler. The soil was then added up to the 10 centimetre interval and compacted with a large pestle, where the pestle was dropped a specific amount of times from a specific height. This was done to ensure a constant and even amount of compaction. At every 20 centimetre interval (every second round of compaction) a sample was taken with a bulk density soil core

sampler (with a known volume). This samples' weight was then measured to ensure that the same density was achieved throughout the process of compaction. This was achieved by using Equation 7 for the density of solids, where ρ_s was the density of the solid measured, M_s was the mass of the solid measured and V_s was the known sample volume taken from the bulk density soil core sampler (Hillel, 2003).

Equation 7: Formula for determining the density of solids (Hillel, 2003).

$$\rho_s = M_s/V_s$$

This process was repeated up until the same mark was reached as the other two drums, once again to ensure that the volume was kept constant. The soil added to this drum had approximately 2% water volume, and this was done to ensure optimal compaction.

After this, the Neutron probe was positioned on top of the drums, above the installed access tubes. All measurement taken for all three the drums was taken at 40 centimetres, to ensure constant and accurate measurements. Three measurements were taken for the water, uncompacted soil and compacted soil. These measurements were recorded by hand and then imported into *Microsoft Excel* for further analyses. By doing this, a laboratory calibration could be done to calculate the absolute density measurements, using the relative density measurements.

3.3.4.3 Density calibration data analysis

By using the calibration protocol measurements, the absolute density measurements can be calculated from the relative density measurements (those taken in the field). This was done by creating a polynomial graph in *Microsoft Excel* (see Figure 17), where the calibration protocol counts were considered the independent values (X-axis) and the calculated density the dependant (Y-axis) values (Campbell *et al.*, 1990; Tokumoto *et al.*, 2012). Tokumoto *et al.* (2012) calculated the calibrated densities by plotting the calculated densities as the independent values and the calibration protocol counts as the dependant values, where in this study the values were inverted. The implications being that the relative measurements were calculated to be calibrated to the known densities of the water, loose soil and compacted soil. The densities of the water, loose soil and compacted soil were calculated with Equation 7, and the volume (V) of the bulk density soil core sampler was calculated with Equation 8.

Equation 8: Equation used for calculating the volume of the bulk density samples with the soil core sampler.

$$V = \pi \cdot r^2 \cdot h$$

By using the polynomial trend line function in *Microsoft Excel*, the following equation was derived

Equation 9: Density calibration equation for determining absolute density.

$$y = 0.1268x^2 + 0.8628x - 0.6495$$

By using Equation 9, the absolute density was calculated, by replacing the x value with the corresponding relative dry density measurement taken in the field. This was done for all the dry density measurements (measured at every 20 centimetre interval for each hole) taken in the field.

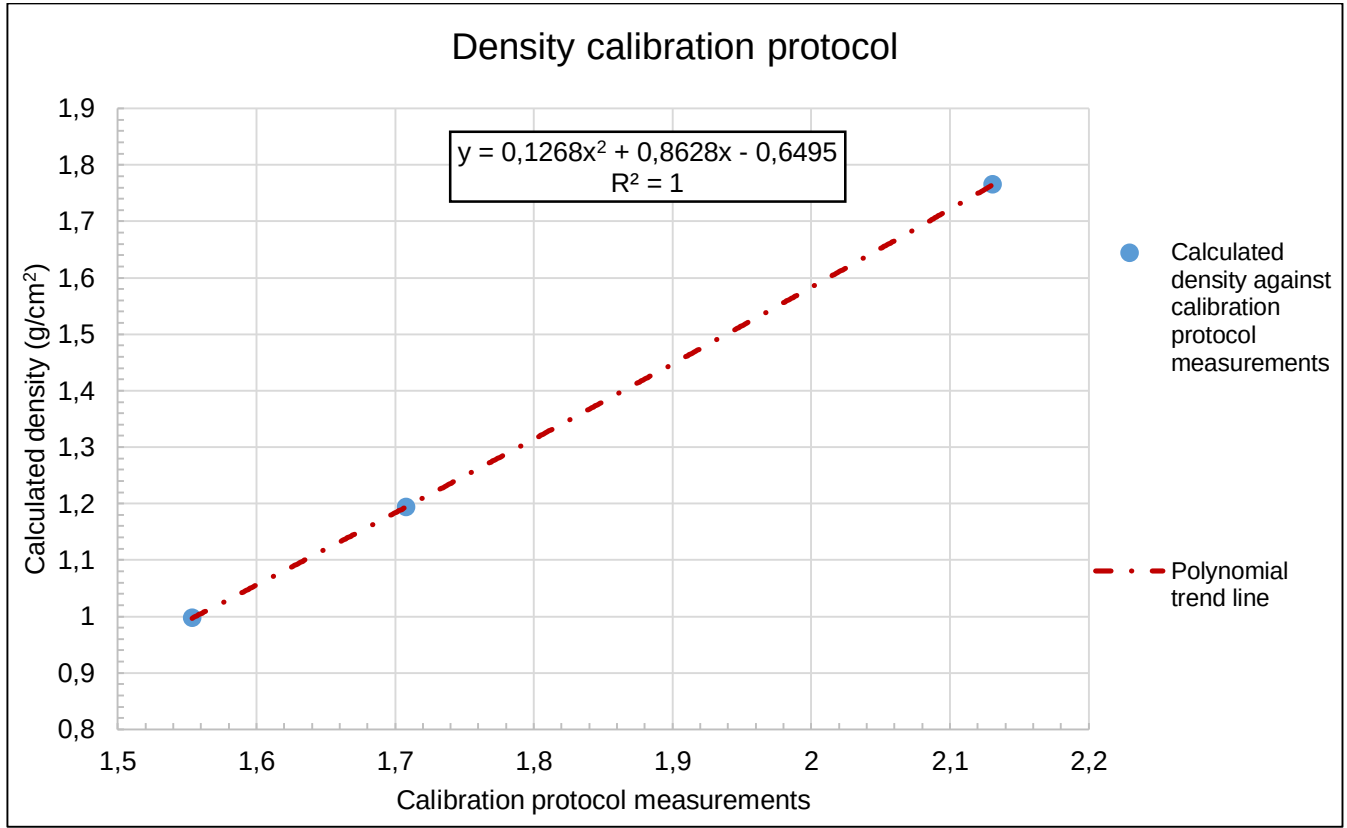


Figure 17: Polynomial graph of calculated densities plotted against the density calibration counts of the Neutron probe.

3.3.4.4 Volumetric calibration data analysis

Firstly, all data was sorted into tables in *Microsoft Excel*, where the data was processed and cleaned (see Appendix 4). The data was processed in such a manner that all profiles and depths had corresponding values. After this, the data was rearranged, as to be displayed on a scatter plot. The volumetric measurements were plotted as the depended (Y-axis) and the Neutron probe counts were plotted as the independent (X-axis) (Campbell *et al.*, 1990; Fayer & Gee, 2005; Kodama *et al.*, 1985; Kodikara *et al.*, 2013; Smith & Mullins, 2001; Tokumoto *et al.*, 2012). In other research done by Campbell *et al.* (1990), Kodama *et al.* (1985) and Tokumoto *et al.* (2012), the volumetric measurements and the Neutron probe counts were plotted as independent and dependant, respectively, as to give the calibrated Count Ratios of the Neutron probe. In this study, the axes were inverted to these research studies, as to give the calibrated volumetric measurements and not the calibrated Count Ratios (Fayer & Gee,

2005). The reason being that the Diviner was also calibrated to give volumetric measurements. By doing this, the data analyses of the different methods could be done with more ease and accuracy.

After the volumetric and Neutron probe counts were plotted on the scatter plot, a linear trend line was added (all the scatterplots were shown in Appendix 4). Looking at the graphs, two slightly different trends can be seen, where the January data is more scattered than the March and June data. This was attributed to the fact that the field caught on fire, and only half of the field burned down. The half of the field that was burned down had slightly lower moisture counts closer to the surface than the other half. The calibration equation and the multiple regression coefficient (R^2) for a) January, b) March and c) June were shown in Equation 10, 11 and 12.

Equation 10: a) Volumetric calibration equation and regression coefficient for January.

$$y = 4 \cdot 10^{-5}x + 0.0429 \text{ and } R^2 = 0.4919$$

Equation 11: b) Volumetric calibration equation and regression coefficient for March.

$$y = 4 \cdot 10^{-5}x + 0.0345 \text{ and } R^2 = 0.5175$$

Equation 12: c) Volumetric calibration equation and regression coefficient for June.

$$y = 4 \cdot 10^{-5}x + 0.026 \text{ and } R^2 = 0.5415$$

In these calibration equations, the x values were replaced with the corresponding raw Neutron probe counts, which resulted in a calibrated volumetric measurement for each depth of all holes. These calibrated volumetric measurements were then used for statistical analyses such as T-tests and analysis of variance (ANOVA), which is discussed later in this chapter.

3.3.5 Diviner 2000

3.3.5.1 Setup and operation

Before using the Diviner in the field, a setup protocol was required (Sentek Propriety Limited, 2009). This included setting the time and date, and calibrating the air count and water count. The time and date were simply set by updating these parameters (in the “status” menu) to the current time and date of usage (Sentek Propriety Limited, 2009). Furthermore, to calibrate the air count, the probe was inserted into an access tube and held at a minimum height of 10 centimetres above ground (Sentek Propriety Limited, 2009). This was done to ensure that there were no solid objects (accept the access tube) near the sensor during the calibration process (Sentek Propriety Limited, 2009). A 10 second reading was taken to calibrate the air count (Sentek Propriety Limited, 2009). It is, however, noteworthy to mention that the access

tube, with the probe, should be held still and at a consistent height of approximately 10 centimetres above ground for the entire period of this calibration (Sentek Propriety Limited, 2009). If this is not done, the measurement might not be completely accurate or an error will occur, after which the air count calibration process needs to be repeated. To calibrate the water count, the probe was inserted into a sealed access tube, which was then submerged into water (Sentek Propriety Limited, 2009). For this step, a 20 litre bucket was filled with water, where a minimum of 10 litres is required for this calibration process (Sentek Propriety Limited, 2009). The access tube (together with the probe) was submerged into the water. It is very important to ensure that the sensor is held very still at a minimum distance of 10 centimetres from the top, bottom and the sides of the bucket (Sentek Propriety Limited, 2009). This is done to ensure that the calibration of the water count is done accurately and correctly (Sentek Propriety Limited, 2009). If the probe is closer than 10 centimetres to the top, bottom or sides of the bucket, the calibration will not be accurate or an error message will occur (in this case the calibration process for the water count needs to be repeated).

As mentioned previously, the Diviner data was collected on a 100 by 100 metre grid, which was predetermined. After the holes had been drilled for the gravimetric and volumetric water content, a PVC access tube was installed. This tube was then sawed off at approximately five centimetres above ground level. To initiate measurements for the Diviner, a profile was created for each hole (Sentek Propriety Limited, 2009). The specific coordinate was noted at each profile, as to ensure that the correct profile was used with each fieldwork session. After the profile has been created, the continuous measurement setting was used to take measurements (Sentek Propriety Limited, 2009). After the continuous measurement prompt has been activated, the probe was slightly inserted into the access tube, as shown in Figure 18 in the top right image. At this point, the control unit gives a command, where the probe is to be set at the starting point (which is at zero centimetres as indicated on the probe rod) (Sentek Propriety Limited, 2009). Thereafter, the probe was inserted into the installed access tube until the bottom of the access tube was reached. The probe was then removed from the tube, and the measurements were saved automatically. Measurements were taken at 10 centimetre intervals (Sentek Propriety Limited, 2009). It is important to insert and remove the probe at a constant and steady rate, to ensure that measurements are taken as accurately as possible (Sentek Propriety Limited, 2009).

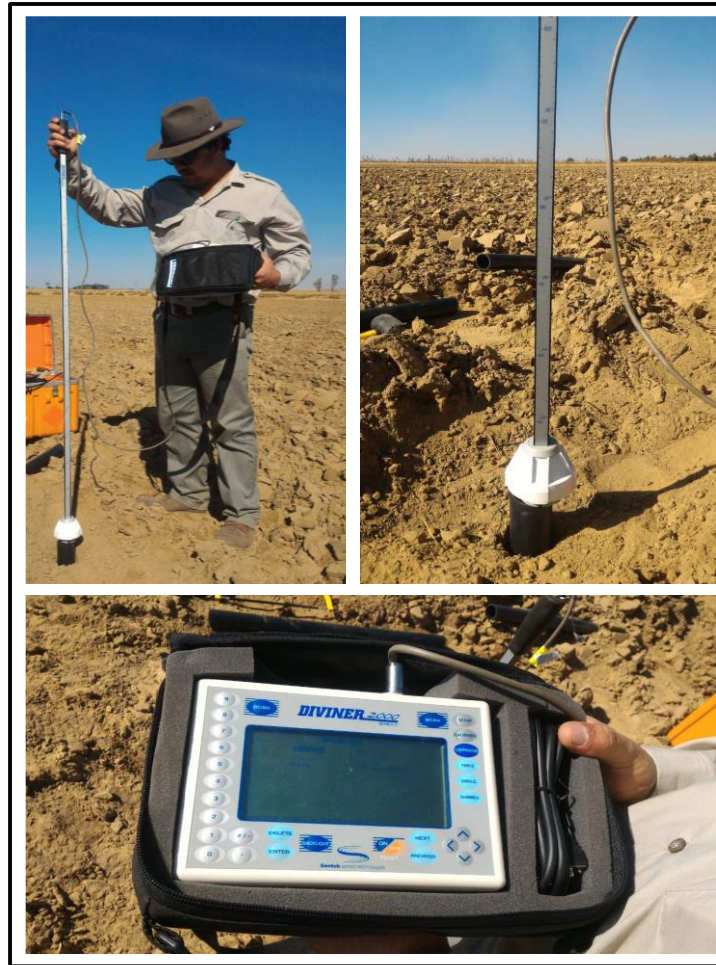


Figure 18: The top left image shows the user holding the 1.6 metre probe rod with the control unit (as the probe is placed at the starting position). The top right image shows the probe, probe rod and the probe cap, once again, at the starting position to take a reading. The bottom image shows the control unit for the Diviner 2000.

The control unit automatically saves the depth of each profile after the first measurement, and every measurement taken (of that specific profile) thereafter, will only measure up until that specific depth (Sentek Propriety Limited, 2009). Thus, the depth of each profile created was recorder by hand. The reason being that in some cases, the access tubes needed to be removed from the soil after each measurement. The recorded depths were then used in the next fieldwork session, to drill the holes to the exact same depth as the first fieldwork session. The access tubes that were removed from the soil were numbered (with the profile number) and reinserted during the next fieldwork session. In the case that water or moisture is present inside the access tube, two sensors located at the bottom of the probe detects this and gives an error that indicates the probe has made direct contact with water (Sentek Propriety Limited, 2009). When tubes were encountered where water or moisture were present, a tool devised specifically for the purpose of removing water from the tubes, was used. This tool consisted of a 2.3 metre pole, which was fitted with a sponge. This pole was then inserted into the access tube until the bottom was reached. The pole was then removed, and the water was pressed

out of the sponge. This process was repeated until all moisture was removed from the installed access tubes.

3.3.5.2 Data analysis

The SF measurements were exported from the Diviner 2000 control unit. The Diviner stores the data in a format (DBK file) that is not supported by software such as *Microsoft Excel*. The files exported from the Diviner were then converted to a usable format (Text file) with software designed specifically for the Diviner 2000 and is freely available on the Sentek website (<https://sentektechnologies.com/download/diviner-2000-utilities-ver-1-8-1/>).

These converted measurements (in Appendix 5) were then imported into *Microsoft Excel* where the data was processed and sorted into tables for further analysis. The calibration of the volumetric measurements were done in a similar manner to the Neutron probe volumetric calibration. The volumetric measurements were plotted as the dependent values (Y-axis) and the scaled frequency measurements were plotted as the independent values (X-axis) (Baumhardt *et al.*, 2000; Burgess *et al.*, 2006; Evett *et al.*, 2002a; Evett *et al.*, 2006; Heng *et al.*, 2002; Mazahrih *et al.*, 2008; Provenzano *et al.*, 2015). This was also done, as to calibrate the SF measurements to a volumetric measurement, to be used in the statistical analysis of the data.

After the data was plotted on a scatterplot graph, the correlation equation and the R^2 values for a) January, b) March and c) June were as follows

Equation 13: a) Diviner 2000 volumetric calibration equation and regression coefficient for January.

$$y = 0.1194x - 0.002 \text{ and } R^2 = 0.4618$$

Equation 14: b) Diviner 2000 volumetric calibration equation and regression coefficient for March.

$$y = 0.1146x - 0.0119 \text{ and } R^2 = 0.3826$$

Equation 15: c) Diviner 2000 volumetric calibration equation and regression coefficient for June.

$$y = 0.232x - 0.0361 \text{ and } R^2 = 0.4383.$$

These equations were then used to acquire the calibrated volumetric measurements, where the SF measurements were used as the x values and the calibrated volumetric measurements were the calculated y values. These calculated volumetric measurements for the Diviner were then used for T-tests and ANOVA tests.

3.4 MONITORING AND ASSESSMENTS

During the course of this study, there were five main field visits. The first field visit (that took place during the December of 2017) was used to determine the specific study area, where preliminary studies were done on the desired centre pivot. These studies were done to, firstly, determine if there was any preliminary hypotheses or noticeable anomalies and, secondly, to determine if there were any specific area of interest. The preliminary study also consisted of the study of satellite imagery, to determine possible areas of interest. While investigating different time periods of satellite imagery, it was noted that certain areas in the field had constant differences in colour. The fact that some areas were constantly a couple of shades darker than the surrounding areas, led to the hypothesis that the subsurface had minor differences. These minor differences were thought to be palaeochannels. According to this, it was determined that Pivot number four should be the main area of study.

On the second field visit in January 2018, the predetermined grids discussed earlier in this chapter, were used to install the access tubes for the Neutron probe and the Diviner. Together with this, soil samples were taken for the gravimetric and volumetric measurements. The data for the CMD Mini-Explorer and CMD Explorer were also collected. It was during this field visit that the Western half of the field caught on fire. The fire was very quickly contained and put out. This put the field work back by two days, but the days lost were caught up and the study remained on track.

For the third field visit (during March 2018), the gravimetric and volumetric soil samples were collected, together with the Neutron probe and Diviner data. Due to the field fire, some of the access tubes needed to be reinstalled, but the coordinates taken during the second field work ensured that the access tubes were easily found and could easily be reinstalled. During this fieldwork, the CMD Mini-Explorer and CMD Explorer could not be used. Therefore, data of the two CMD apparatuses could not be collected. The density measurements were also collected with the Neutron probe, where the density calibration protocol took place shortly after the fieldwork.

The soil mapping for Pivot four took place during the fourth field visit (in May 2018). Where a hydraulic drill, fitted on a vehicle, was used to drill for soil observation (to determine the soil type). The data for the soil profiles were collected using a GPS unit, where all details and description of the soil profiles were stored on the GPS unit together with the exact coordinates of the holes drilled. The mapping of the soils were loosely based on the grid system used for the gravimetric, volumetric, Neutron probe and Diviner data. Although the holes were drilled on this 100 by 100 metre grid, extra holes were drilled where two neighbouring soil types were found. This was done to ensure the highest possible accuracy and resolution of the soil map for the pivot under investigation. This data collected was then sent to the Omnia headquarters

in South Africa, located in Pretoria. The data were analysed and sent back in shapefile formats, where these files were then used to create the soil map, of pivot four, in *ArcGIS 10.3*.

On the fifth and final field visit, during the month of June 2018, the final gravimetric, volumetric, Neutron probe and Diviner data was collected. During this field visit, the CMD Mini-Explorer and CMD Explorer data was also collected. After this field visit, the data was imported into *Microsoft Excel* and analysed as discussed previously in this chapter.

3.5 STATISTICAL PROCESSING METHODS

After exporting the CMD Mini-Explorer and CMD Explorer data to *Microsoft Excel*, the data was processed in *ArcGIS 10*, the errors were delineated and fixed and exported back to *Microsoft Excel* (as discussed in section 3.3.2.2). After cleaning the data, it was then imported into *Surfer 11*. The data was then displayed as a longitude (X) and latitude (Y) map. The apparent conductivity data for each depth measured, as discussed in Chapter 2 for both the CMD Mini-Explorer and CMD Explorer, was processed with the Kriging (Point Kriging) interpolation tool in *Surfer 11* (all the semi-variograms and variogram reports were shown in Appendix 7). The data was then displayed with the same colour scheme, and set to the same scale. By doing this, the extent of the anomalies could be accurately displayed and discussed. After this, the maps created were exported and saved to *Microsoft Excel*, to represent the visual results as the January- and June CMD Mini-Explorer and CMD Explorer data. The maps were represented in table format to show each apparatus and depth clearly.

The visual representations of the volumetric-, Neutron probe- and Diviner data were processed in a similar manner as the CMD data. The data were sorted into tables, where every 20 centimetre interval for each apparatus was used. This was done due to the fact that the Diviner takes readings at every 10 centimetre interval, and the Neutron probe and volumetric data were collected at every 20 centimetre interval. This makes the processing and visualisation of the data easier to represent and discuss. Furthermore, the data was also interpolated using the Kriging tool, the values were assigned to the same, consistent colour scheme and the scale was kept the same for all three the methods (i.e. volumetric, Neutron probe and Diviner).

For the statistical processing and analyses of the volumetric-, Neutron probe- and Diviner data, T-tests (assuming unequal variance) and ANOVA tests were done. The CMD data was excluded from the T-tests due to two reasons, firstly the dataset sizes varied too much (e.g. the volumetric, Neutron probe and Diviner had 229 data counts and the CMD Mini-Explorer had 50836 data counts), and it was seen that the T-tests did not work with such large amounts of data. Due to the large differences in data counts, the measurements taken by the CMD apparatuses on – or as close as possible to – the coordinates of the measurements taken by

the other apparatuses were extracted. This was done by simply highlighting the corresponding coordinates of the measurements taken by the CMD apparatuses in *ArcGIS 10.1* and extracting the data to an *Excel* spreadsheet. The second reason was that, even with the correct data size, the depths of the measurement taken by the CMD apparatuses and the other apparatuses were not the same. The CMD Mini-Explorer took measurements at 0.5 metres, one metre and 1.8 metres, and the other apparatuses took measurements every 20 centimetres up to a depth of 1.2 metres. This also caused a difference in data sizes, where the other apparatuses now had more data points than the CMD apparatuses, and as mentioned above the T-tests did not work with different dataset sizes. The CMD data was, however, included in the ANOVA tests.

The T-tests and ANOVA tests were done using the 'analysis tool pack' add-in for *Microsoft Excel*. Firstly, three T-tests were done for each of the three months. A T-test was done for a) volumetric measurements tested against Neutron probe calibrated volumetric measurements, b) volumetric measurements tested against Diviner calibrated volumetric measurements and, finally, c) Neutron probe calibrated volumetric measurements tested against Diviner calibrated volumetric measurements. The results were then represented in table format. For all the T-tests, an alpha (α) value of 0.05 was chosen. The T-test results included the mean of each data group, the variance of each data group, the number of observations of each data group, the hypothesized mean difference of zero (0) and the degrees of freedom (df). Furthermore, the T-statistic (T-stat), the p-value for the one-tail analysis, the T-critical one-tail analysis, the p-value for the two-tail analysis, and finally, the T-critical value for the two-tail analysis were also discussed.

For all the T-test analyses done, two hypotheses were formulated. The first, $H_0: \mu_1 = \mu_2$, where μ represents one dataset (e.g. μ_1 could represent the January volumetric dataset and μ_2 represents the January Neutron probe dataset). Therefore, H_0 (also referred to as the Null hypothesis) suggests that dataset one and dataset two are the same, or are very alike. H_0 therefore suggests that there is a good statistical probability that the two datasets will show the same results. This suggests that, when the $p\text{-value} > \alpha$, the H_0 hypothesis will be proven as true, or rather that H_0 will be accepted. The alternative is that $H_1: \mu_1 \neq \mu_2$, where μ once again represents one dataset. H_1 (also referred to as the alternative, or the alternative hypothesis) suggests that there is no, or very little, statistical probability that the two datasets will show the same results. Thus, when the $p\text{-value} < \alpha$, the Null hypothesis will be rejected or rather, the alternative hypothesis will be accepted. This was done to determine whether there is a probability that different methods used would result in similar and reliable results. Thus showing that if, for instance, one only uses the Diviner 2000 without any other of the other tested methods, the results of the apparatus can be trusted and it is not necessary to use more than one method to determine the SMC of the soil tested.

Two sets of ANOVA tests were done, firstly ANOVA analyses were done for each month which included the volumetric measurements, Neutron probe calibrated volumetric measurements and the Diviner calibrated volumetric measurements, but excluded the CMD data. Secondly, ANOVA analyses were done for January and June (as the CMD data was only available for these two months) where all the datasets were included. The reason for doing two sets of ANOVA analyses (one including the CMD data, and one excluding the CMD data) was due to the apparatuses and methods giving the measurements in different outputs. The CMD measurements were given in EC (milliSiemens per metre) and all the other methods' results were given as volumetric water content. The CMD results were used as is (as opposed to being converted to apparent volumetric water content), because the third aim of this study was to compare the results to see which apparatus would be suitable for different uses or circumstances.

All the ANOVA analyses were discussed in two parts. Firstly, as the summary of the data (volumetric, Neutron probe and Diviner), and secondly the results for the ANOVA analysis. Firstly, the counts (number of measurement data), the sum (the sum of all the values), the average (the average of all the values) and variance results were given as a summary in table format. Secondly, the sum of squares (SS), the df , the F-critical value, also referred to as the F-statistic – hereon referred to as F-stat (F), the calculated probability (p-value) and the F-critical value were discussed.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

The results shown in this chapter were obtained by the processing of the data as outlined in Chapter 3. These results were used to show the individual geophysical methods' measurements, and to measure the statistical probabilities between the different geophysical methods used, also showing the accuracy of the differing methods (as compared to the volumetric soil moisture contents).

4.2 RESULTS AND DISCUSSION

4.2.1 T-test analyses of the volumetric-, Neutron probe- and Diviner 2000 measurements

As mentioned in Chapter 3, two hypotheses were formulated. Firstly the Null hypothesis, $H_0: \mu_1 = \mu_2$, suggesting that dataset one and dataset two are the same, or are very alike. Secondly the alternative hypothesis, $H_1: \mu_1 \neq \mu_2$, suggesting that there is no, or very little, statistical probability that the two datasets will show the same results.

4.2.1.1 January T-test analyses

Table 3 shows the results for the T-test done between the volumetric- and Neutron probe measurements. There was a negligible difference in the mean (0.0003) and variance (0.0009) of the January data analysis. A sample size of 229 ($n=229$) was used for both datasets, and a df of 416 was observed. For the one-tail test, a p-value of 0.47 was achieved, which shows that there was a good probability that the two datasets would show the same results. The same could be said for the two-tail test that showed a p-value of 0.94, which was much higher than the α (0.05) value. Therefore, the H_0 hypothesis was accepted. This claim was further proven with the T-stat being much smaller than the T-critical value in both cases (referring to both the one-tail and two-tail values in Table 3).

Table 3: Two-sample T-test analysis, assuming unequal variance, for volumetric- and Neutron probe measurements for January.

T-test: Two-Sample Assuming Unequal Variances		
	Volumetric measurements	Neutron probe measurements
Mean	0.092018877	0.091734585
Variance	0.001870055	0.000980347
Observations	229	229
Hypothesized Mean Difference	0	
df	416	
T-stat	0.080580447	
P(T<=t) one-tail	0.467907184	
T-critical one-tail	1.648524754	
P(T<=t) two-tail	0.935814368	
T-critical two-tail	1.965682905	

The two-sample T-test for the volumetric- and Diviner measurements were shown in Table 4. The difference in the mean (0.001) and the variance (0.001) were also very minor, and was seen as insignificant. The same amount of observations (n=229) were used for this analysis and the *df* was 394. The one-tail analysis had a p-value of 0.38, and the two-tail analysis had a p-value of 0.76. Although both these p-values were less than the previous analysis, the p-values were still higher than the α value of 0.05. For this reason the H_0 hypothesis was accepted, and there was a good probability that Diviner measurements would give accurate results, compared to the volumetric measurements. This statement was further shown as accurate, looking at the T-stat (0.31) that was much lower than the T-critical values in both cases.

Table 4: Two-sample T-test, assuming unequal variance, for volumetric- and Diviner 2000 measurements for January.

T-test: Two-Sample Assuming Unequal Variances		
	Volumetric measurements	Diviner measurements
Mean	0.092018877	0.090960978
Variance	0.001870055	0.000804961
Observations	229	229
Hypothesized Mean Difference	0	
df	394	
T-stat	0.309527397	
P(T<=t) one-tail	0.378542002	
T-critical one-tail	1.648730226	
P(T<=t) two-tail	0.757084005	
T-critical two-tail	1.966003201	

The T-test analysis for the Neutron probe- and Diviner measurements (see Table 5) had a mean difference of 0.0008 and a difference in variance of 0.0002, which was considered as

an insignificant difference in both cases. The sample size was the same as the other analyses for January, with a df of 452. The p-values for both the one-tail and two-tail analyses were 0.39 and 0.78 respectively. In both cases, the p-value was higher than the α value. Once again, the T-stat (0.28) was much lower than the one-tail- (1.65) and two-tail critical (1.97) values. For this reason, the H_0 hypothesis was accepted, and the two datasets have a good probability that the measurements would be the same if either one of these methods were used alone.

Table 5: Two-sample T-test, assuming unequal variance, for Neutron probe- and Diviner 2000 measurements for January.

T-test: Two-Sample Assuming Unequal Variances		
	<i>Neutron probe measurements</i>	<i>Diviner measurements</i>
Mean	0.091734585	0.090960978
Variance	0.000980347	0.000804961
Observations	229	229
Hypothesized Mean Difference	0	
df	452	
T-stat	0.277065139	
P(T<=t) one-tail	0.390928376	
T-critical one-tail	1.64823176	
P(T<=t) two-tail	0.781856752	
T-critical two-tail	1.965226215	

Looking at all the T-tests done for the month of January, the H_0 hypotheses were accepted in each case. This shows that the Neutron probe and the Diviner could have been used to measure the SMC accurately, without comparing the results with the volumetric measurements. The statistic difference in the means and variances were very small in all three cases, and was seen as insignificant differences. In all three cases, the p-values were higher than that of the α value, and this statement was further tested by looking at the T-stat and how it compared to the T-critical values. For this reason, the alternative hypothesis was rejected (and the Null hypothesis accepted) in all three the T-tests, because the results of the datasets showed to be very similar.

4.2.1.2 March T-test analyses

Table 6 shows the results of the T-test analysis done for the volumetric- and Neutron probe measurements taken in March. The difference in the two means of the measurements were 0.002, and the difference in the variances were 0.0009. For all the March T-test analyses, the sample sizes were 246 ($n=246$), and the df for this T-test was 438. Looking at the one-tail analysis, the p-value was 0.22, and the p-value for the two-tail analysis was 0.44. Both p-

values were higher than the α , which shows that the H_0 hypothesis was accepted. Furthermore, the T-stat value for this analysis was 0.77, which was smaller than both the one-tail and two-tail T-critical values. This further proves that there was a statistical probability of the Neutron probe yielding similar results to the volumetric measurements.

Table 6: Two-sample T-test, assuming unequal variance, for volumetric- and Neutron probe measurements for March.

T-test: Two-Sample Assuming Unequal Variances		
	<i>Volumetric measurements</i>	<i>Neutron probe measurements</i>
Mean	0.078435632	0.075989756
Variance	0.001670271	0.000815582
Observations	246	246
Hypothesized Mean Difference	0	
df	438	
T-stat	0.769421529	
P(T<=t) one-tail	0.221028919	
T-critical one-tail	1.648339967	
P(T<=t) two-tail	0.442057837	
T-critical two-tail	1.965394872	

The T-test analysis between the volumetric- and Diviner measurements, shown in Table 7, had a difference in both the mean- and variance of 0.001. The df , in this case, was found to be 414. The T-stat was 0.46, and in both cases it was lower than the one-tail- and two-tail T-critical values. The one-tail and two-tail p-values were 0.32 and 0.65 respectively. In both these cases, the p-values were higher than α . For this reason, the H_0 hypothesis was accepted, and it was presumed that the two datasets had a good probability of giving similar results.

Table 7: Two-sample T-test, assuming unequal variance, for volumetric- and Diviner 2000 measurements for March.

T-test: Two-Sample Assuming Unequal Variances		
	<i>Volumetric measurements</i>	<i>Diviner measurements</i>
Mean	0.078435632	0.077032287
Variance	0.001670271	0.000667803
Observations	246	246
Hypothesized Mean Difference	0	
df	414	
T-stat	0.455200833	
P(T<=t) one-tail	0.324601693	
T-critical one-tail	1.648542529	
P(T<=t) two-tail	0.649203385	
T-critical two-tail	1.965710612	

The final T-test analysis done for March was shown in Table 8. Here the difference between the mean and the variance was 0.001 and 0.0001 respectively. The df , for the March analysis of the Neutron probe- and Diviner measurements, was 485. Here, the T-stat was -0.42, which was significantly smaller than both the T-critical one-tail (1.65) and two-tail (1.96) values. The one-tail p-value was 0.34 and the two-tail p-value was 0.67, which was larger than the α in both cases. Looking at these results, the H_0 hypothesis was once again accepted, and the datasets had a moderate to good probability of having similar results.

Table 8: Two-sample T-test, assuming unequal variance, for Neutron probe- and Diviner 2000 measurements for March.

T-test: Two-Sample Assuming Unequal Variances		
	<i>Neutron probe measurements</i>	<i>Diviner measurements</i>
Mean	0.075989756	0.077032287
Variance	0.000815582	0.000667803
Observations	246	246
Hypothesized Mean Difference	0	
df	485	
T-stat	-0.424550589	
P(T<=t) one-tail	0.335676292	
T-critical one-tail	1.648001465	
P(T<=t) two-tail	0.671352584	
T-critical two-tail	1.964867287	

The H_0 hypothesis was accepted for all the analyses done in the month of March. Overall, the differences in the mean and variance values were insignificantly small. The p-values for the month of March was overall the lowest, and the reason therefore was uncertain. A possible explanation was the rainfall that was encountered during the data collection. The data was most likely affected as a part of the field was sampled and measurements were already taken before the rainfall occurred, and the rest of the samples and measurements were taken after the rainfall. This can be seen when looking at the volumetric measurements for March.

4.2.1.3 June T-test analyses

Table 9 shows the results of the T-test done for the volumetric- and Neutron probe measurements taken during the month of June. The difference in the two means were 0.001 and the difference in the variances were 0.0006. The sample size for all the June analyses were 253 ($n=253$) and the df for this T-test was 469. For this analysis, the one-tail p-value was 0.35 and the two-tail p-value was 0.7. The p-values were higher than α in both cases, therefore the Null hypothesis was accepted. This was further proven by the T-stat (-0.39) being much smaller than both the one-tail (1.65) and two-tail (1.97) T-critical values.

Table 9: Two-sample T-test, assuming unequal variance, for volumetric- and Neutron probe measurements for June.

T-test: Two-Sample Assuming Unequal Variances		
	Volumetric measurements	Neutron probe measurements
Mean	0.067806943	0.068977549
Variance	0.001474531	0.000840801
Observations	253	253
Hypothesized Mean Difference	0	
df	469	
T-stat	-0.386958729	
P(T<=t) one-tail	0.349481141	
T-critical one-tail	1.648109068	
P(T<=t) two-tail	0.698962281	
T-critical two-tail	1.965034989	

Looking at the volumetric- and Diviner measurements for June, in Table 10, the difference in the means were 0.0003 and the difference in variance was 0.0008. In this T-test analysis, the *df* was found to be 437. The T-stat was 0.11, which was smaller than the one-tail (1.65) and two-tail (1.97) T-critical values. Looking at the p-values, the one-tail test was 0.46 and the two-tail test was 0.92. Considering both the T-stat values and the p-values, it was found that these datasets had a good statistical probability of yielding similar results (H_0 was accepted).

Table 10: Two-sample T-test, assuming unequal variance, for volumetric- and Diviner 2000 measurements for June.

T-test: Two-Sample Assuming Unequal Variances		
	Volumetric measurements	Diviner measurements
Mean	0.067806943	0.067500299
Variance	0.001474531	0.000646839
Observations	253	253
Hypothesized Mean Difference	0	
df	437	
T-stat	0.10589756	
P(T<=t) one-tail	0.457856111	
T-critical one-tail	1.648347961	
P(T<=t) two-tail	0.915712222	
T-critical two-tail	1.965407333	

Finally, Table 11 shows the analysis done for the Neutron probe- and Diviner T-test, for the measurements taken during the month of June. In this analysis, the difference in the two means and variances were 0.001 and 0.0002 respectively, and the *df* was 496. This T-test analysis had the overall lowest one-tail p-value (0.27) of all the T-tests done, and the two-tailed analysis p-values (0.54) had the second lowest p-value. Even though these two p-values are considered the lowest and second lowest, the Null hypothesis was still accepted. The

reason being that the p-values were still higher than α . This was proven to be accurate, because the T-stat (0.61) was still lower than both the one-tail (1.65) and the two-tail (1.96) T-critical values.

Table 11: Two-sample T-test, assuming unequal variance, for Neutron probe- and Diviner 2000 measurements for June.

T-test: Two-Sample Assuming Unequal Variances		
	<i>Neutron probe measurements</i>	<i>Diviner measurements</i>
Mean	0.068977549	0.067500299
Variance	0.000840801	0.000646839
Observations	253	253
Hypothesized Mean Difference	0	
df	496	
T-stat	0.609207662	
P(T<=t) one-tail	0.271332868	
T-critical one-tail	1.647931523	
P(T<=t) two-tail	0.542665736	
T-critical two-tail	1.964758283	

For the June analyses, the Null hypothesis was accepted in every test (as was the case for January and March). The Neutron probe- and Diviner measurements had the overall lowest one-tail p-value, with 0.27, and the second lowest two-tail p-value with 0.54. This was likely due to human error with capturing of the Neutron probe measurements, although no difficulties were faced during the fieldwork and collecting of the data. The possibility of errors are presumed to be in the Neutron probe dataset, because the T-tests which included the Neutron probe both had the lowest p-values for June. Even considering the fact that this test yielded the lowest and second lowest p-values, H_0 was still accepted for all the June analyses showing a positive probability of yielding similar results.

4.2.2 ANOVA analyses for the volumetric-, Neutron probe- and Diviner 2000 measurements

The two hypotheses formulated was the same as in the previous section for the T-test analyses. The first hypothesis, the Null hypothesis (H_0), was $H_0: \mu_1 = \mu_2$. The second hypothesis, the alternative hypothesis (H_1), was $H_1: \mu_1 \neq \mu_2$. As with the T-test analyses, the μ for the ANOVA analyses represent a dataset. The Null hypothesis states that there was a good probability that the datasets would yield the same results and be reliable. The alternative hypothesis states that the datasets would not have similar results. In the case that the p-value $> \alpha$, H_0 was accepted, and in the case where the p-value $< \alpha$, H_1 was accepted, or rather H_0 was rejected.

4.2.2.1 January ANOVA analysis, excluding CMD data

Table 12 shows the ANOVA analysis for the January datasets (which included the volumetric- Neutron probe- and Diviner measurements). The sample size of this analysis was 229 (n=229) for all three datasets. The summary in Table 12 shows the sum, average and the variance of a) volumetric measurements, b) Neutron probe measurements, and c) Diviner measurements. The sum for the three datasets were a) 21.07, b) 21.01 and c) 20.83. For a, b and c the averages were 0.09. Finally, the variances for the datasets were a) 0.002, b) 0.001 and c) 0.001.

The ANOVA results showed that the SS between the groups were 0.0001, and within the groups 0.83. The *df* between the three groups were two, and within the groups it was 684. The MS between the three groups were 0.0001 and within the groups it was 0.001. The p-value for the January analysis was 0.95, which was larger than α . When looking at the F-stat (0.06) it was much smaller than the F-crit value (3.01). Therefore, H_0 was accepted and this showed that there was a very good statistical probability that the different datasets would have similar results.

Table 12: ANOVA analysis for the volumetric-, Neutron probe- and Diviner datasets, done for the month of January.

ANOVA: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Volumetric measurements	229	21.072322	0.0920188	0.0018700		
Neutron probe measurements	229	21.00722	0.0917345	0.0009803		
Diviner measurements	229	20.830063	0.0909609	0.0008049		
ANOVA						
Source of Variation	SS	df	MS	F-stat	p-value	F-crit
Between Groups	0.0001372	2	6.86406E-05	0.0563341	0.94522763	3.00889115
Within Groups	0.8334226	684	0.00121845			
Total	0.8335599	686				

4.2.2.2 March ANOVA analysis, excluding CMD data

The March ANOVA analysis between the volumetric-, Neutron probe- and Diviner measurements were shown in Table 13. For all the datasets, the sample size used was 246 (n = 246). In the summary, the sum, average and variance for a) volumetric measurements b) Neutron probe measurements and c) Diviner measurements were calculated. The calculated sum for a, b and c was 19.3, 18.69 and 18.95 respectively. The average for a, b and c, was calculated as 0.08. The variances for the dataset was a) 0.002, b) 0.001 and c) 0.001.

The SS, for the March ANOVA analysis, between the groups were 0.0007 and within the groups, it was 0.77. Between the three groups, the *df* was two and within the groups it was 735. The MS between the three groups were calculated as 0.0004, and within the groups, MS was calculated as 0.001. The Null hypothesis was accepted for the March analysis, because the p-value was found to be 0.7, which is larger than α . This was also seen with the F-stat (0.35) value being smaller than the F-crit value (3.01).

Table 13: ANOVA analysis for the volumetric-, Neutron probe- and Diviner datasets, done for the month of March.

ANOVA: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Volumetric measurements	246	19.29516	0.0784356	0.0016702		
Neutron probe measurements	246	18.69348	0.0759897	0.0008155		
Diviner measurements	246	18.94994	0.0770322	0.0006678		
ANOVA						
Source of Variation	SS	df	MS	F-stat	p-value	F-crit
Between Groups	0.0007411	2	0.00037058	0.352525	0.7030297	3.0079756
Within Groups	0.7726457	735	0.001051219			
Total	0.7733868	737				

4.2.2.3 June ANOVA analysis, excluding CMD data

The sample count for the June ANOVA analysis (see Table 14) was 253 ($n = 253$). The sum of a) volumetric measurements, b) Neutron probe measurements and c) Diviner measurements were 17.16, 17.45 and 17.08 respectively. The averages for a) and c) were 0.068, and for b) it was 0.069. The variances between the groups were calculated as a) 0.0015, b) 0.0008 and c) 0.0006.

The June results showed that the SS between the groups were 0.0003 and within the groups it was calculated as 0.75. The *df* between the groups were, once again, two and within the groups, it was calculated as 756. The F-stat for this analysis was 0.16 and the F-crit value was 3.01. The p-value for the June analysis was calculated as 0.86. Seen as the F-stat was smaller than the F-crit value, and the p-value was larger than α , H_0 was accepted.

Table 14: ANOVA analysis for the volumetric-, Neutron probe- and Diviner datasets, done for the month of June.

ANOVA: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Volumetric measurements	253	17.15515	0.06780	0.00147		
Neutron probe measurements	253	17.45132	0.06897	0.00084080		
Diviner measurements	253	17.07757	0.06750	0.0006468		
ANOVA						
Source of Variation	SS	df	MS	F-stat	p-value	F-crit
Between Groups	0.000307	2	0.000153	0.15572945	0.855818	3.007634
Within Groups	0.746467	756	0.000987		1	6
			9			
Total	0.746774	758				

4.2.2.4 January ANOVA analysis, including CMD data

Table 15 shows the ANOVA analysis for January, with the CMD data included. In this analysis the sample sizes differed, due to the depth limitations of the different apparatuses. The volumetric-, Neutron probe- and Diviner data each had 229 measurements, where the CMD Mini-Explorer had 139 and the CMD Explorer had 171 measurements. The measurements of the apparatuses differed drastically, with the volumetric-, Neutron probe- and Diviner data having an average of roughly 21. The CMD Mini-Explorer had an average of 1718 and the CMD Explorer had an average of 2385. This makes it clear that the outputs of the measurements taken for these apparatuses differed. The averages and variances also drastically differ, as seen in Table 15.

The SS between the groups were 37106.79 and within the groups, it was 10984.75. The *df* between the groups were four and within the groups, it was 992. The MS between the groups and within the groups were 9276.7 and 11.07, respectively. The p-value for this analysis was zero. The F-stat, in this case, was 837.75 and was larger than the F-crit value (2.38). Considering this, H_1 was accepted and these datasets had no statistical probability of yielding similar results.

Table 15: January ANOVA analysis for the volumetric-, Neutron probe-, Diviner-, CMD Mini-Explorer and CMD Explorer.

ANOVA: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Volumetric measurements	229	21.07232	0.09202	0.00187		
Neutron probe measurements	229	21.00722	0.09173	0.00098		
Diviner measurements	229	20.83006	0.09096	0.000805		
Mini-Explorer measurements	139	1718.3	12.3619	31.86479		
Explorer measurements	171	2385.24	13.9488	38.74455		
ANOVA						
Source of Variation	SS	df	MS	F-stat	p-value	F-crit
Between Groups	37106.79477	4	9276.7	837.7512	0	2.38090
Within Groups	10984.74778	992	11.0733			
Total	48091.54255	996				

4.2.2.5 June ANOVA analysis, including CMD data

The results for the June ANOVA analysis, which included the CMD data, was shown in Table 16. The sample size for the volumetric-, Neutron probe- and Diviner datasets were 253, and for both the CMD Mini-Explorer and CMD Explorer the sample size was 177. The sum of the different datasets also differed immensely, with the first three datasets (volumetric, Neutron probe and Diviner) having a sum of about 17 and the CMD Mini-Explorer having a sum of 1062.77 and the CMD Explorer 2485.93. The averages and variances of the different datasets also had large differences (see Table 16).

The SS between the groups, for this analysis, were 29652.47 and within the groups it was 9979.99. The *df* between the groups was four and within the groups, it was 1108. The MS within the groups were 9.01 and between the groups, the MS was 7413.12. The p-value for this analysis was also zero, the same as in the January ANOVA analysis. The F-stat was 823.02 and the F-crit value was 2.38, which was very similar to the previous analysis. Therefore, the alternative hypothesis was accepted.

Table 16: June ANOVA analysis for the volumetric-, Neutron probe-, Diviner-, CMD Mini-Explorer and CMD Explorer.

ANOVA: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Volumetric measurements	253	17.15515	0.06780	0.00147		
Neutron probe measurements	253	17.45132	0.06897	0.00084		
Diviner measurements	253	17.07757	0.06750	0.00064		
Mini-Explorer measurements	177	1062.77	6.00435	5.61454		
Explorer measurements	177	2485.93	14.04480	51.0857		
ANOVA						
Source of Variation	SS	df	MS	F-stat	p-value	F-crit
Between Groups	29652.46894	4	7413.11723	823.02023	0	2.37996
Within Groups	9979.990236	1108	9.00721			
Total	39632.45918	1112				

For both the ANOVA analyses that included the CMD data, the p-values were zero and the F-stat values were much larger than the F-crit values in both cases. This showed that when the CMD data was included in the statistical analyses, the datasets had no statistical probability of yielding similar results. This is due to the different outputs that the measurements are given for the different apparatuses. The volumetric-, Neutron probe- and Diviner measurements were given as volumetric water content and the CMD data was given as mS/m (milliSiemens per metre).

4.2.3 Visual comparisons between the CMD Mini-Explorer, CMD Explorer, volumetric, Neutron probe and Diviner data

In this section the maps created with *Surfer 11*, as mentioned in Chapter 3, were discussed. The data used to create these maps were the same as those used for the T-test and ANOVA analyses. The anomalies visible were discussed, compared and explained. The depths discussed for the CMD Mini-Explorer and CMD Explorer differed from those of the volumetric, Neutron probe and Diviner. The reason therefore, as discussed in Chapter 2, was due to the physical limitations of the different apparatuses and methods used. The CMD Mini-Explorer data was shown at 0.5 metres, one metre and 1.8 metres below the Earth's surface. The CMD Explorers' data was shown at 2.2 metres, 4.2 metres and 6.7 metres below the Earth's surface.

The volumetric- and Neutron probe measurements were collected at 20 centimetre intervals and the Diviner measurements were taken at 10 centimetre intervals. For the analysis and discussion of the visual data, the results were shown at 20 centimetre intervals (20 centimetres to 100 centimetres). The measurements deeper than 100 centimetres (for the volumetric-, Neutron probe- and Diviner data) were not enough in most cases to show the data accurately. The maps' shape and results became warped and unreliable at depths deeper than 100 centimetres due to the Kriging process used. For this reason, the data for these depths were not discussed in detail, but can be seen in Appendix 6. The data for the volumetric, Neutron probe and Diviner were discussed together (as per depth of measurement) for each of the three months

The three general anomalies discussed were shown in Figure 19. As in the case of the second and third anomalies, two or more smaller anomalies could be seen. These smaller anomalies were grouped and discussed as a single anomaly. The reason being that the grouped anomalies were a result of the same phenomenon, and was therefore better discussed as a single larger anomaly.

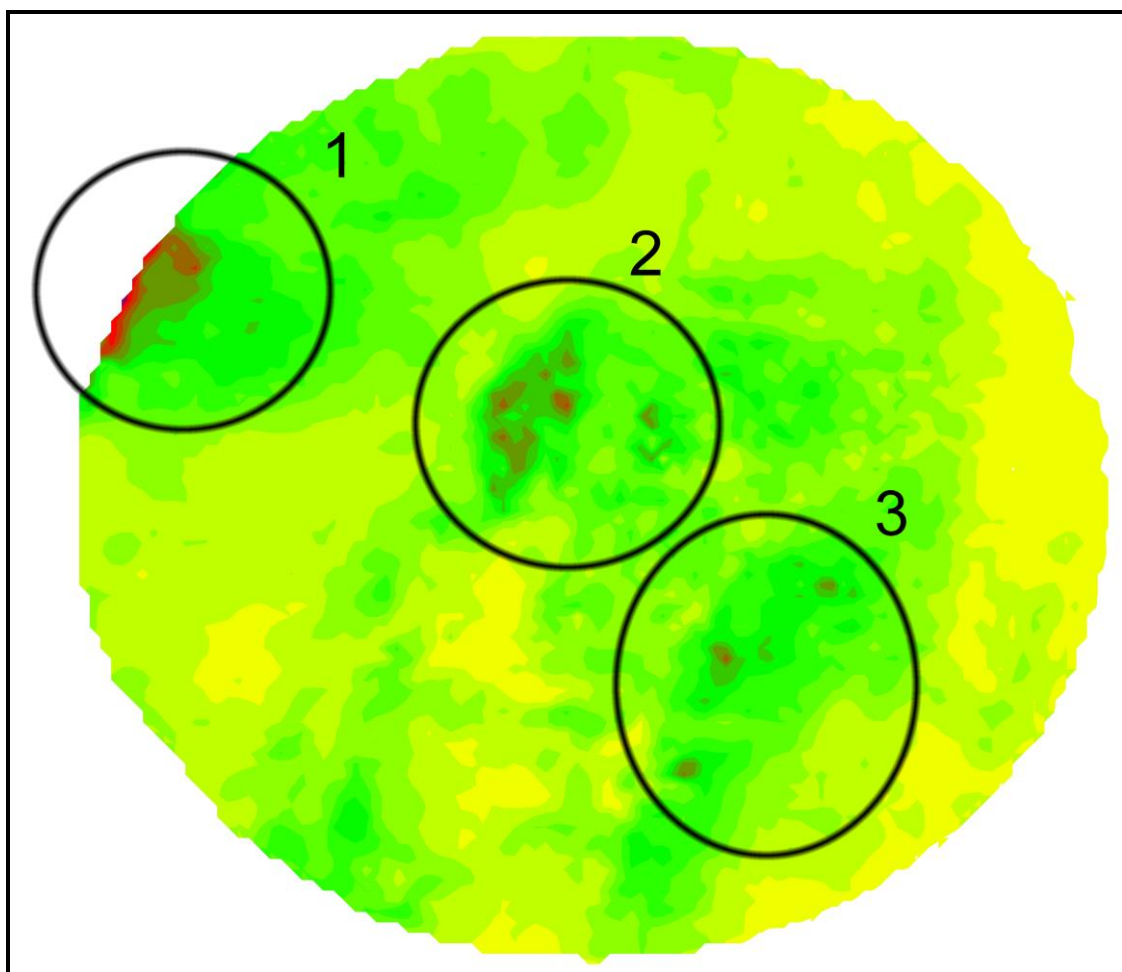


Figure 19: The three anomalies discussed in the study, shown on a map of the January CMD Mini-Explorer measurements at a depth of one metre. The first anomaly could be seen to the Northwest of the pivot, the second anomaly was in the centre of the pivot, and finally, the third anomaly was seen to the Southeast of the pivot.

4.2.3.1 CMD Mini-Explorer and CMD Explorer data for January

Looking at the CMD Mini-Explorer's data for January (in Figure 20), three very small anomalies could be seen, although at this depth they are not major. The first anomaly was seen to the Northwest of the pivot (top left). The second anomaly was seen at the centre of the pivot, and the third anomaly could be seen to the Southeast (bottom right of the field). All three the anomalies become more apparent at a depth of one metre. This showed that as the depth increased, the SMC also increased. At a depth of 1.8 metres, the first anomaly (to the Northwest) increased with this increase of depth, while the surrounding soils had a decrease in SMC. The second and third anomaly both decreased in magnitude from the depth of one metre to 1.8 metres. This showed that there was an accumulation of water between one and 1.8 metres. This decrease of SMC with increasing depths, was due to a restrictive layer that was found between these depths. This restrictive layer is thought to be a palaeochannel. Although it is speculated that there is a palaeochannel present, it was beyond the scope of this study to conduct further research on this topic.

At a depth of 2.2 metres (looking at the CMD Explorer's data in Figure 20), the first anomaly was still increasing with an increase of depth. The second and third anomalies were also still present, although they were becoming smaller and less noticeable. At 4.2 metres, the first anomaly increased both in size and magnitude. The second and third anomalies (at 4.2 metres) were both still visible, although the second anomaly in the centre of the pivot decreased dramatically. At 6.7 metres, the second and third anomalies decreased, so much so that they were almost negligible. The first anomaly increased drastically and shows the possibility of lateral movement of water in a South-westerly direction at this depth. This lateral movement of water was caused due to the topography of the area, where the water generally flows in the direction of the river.

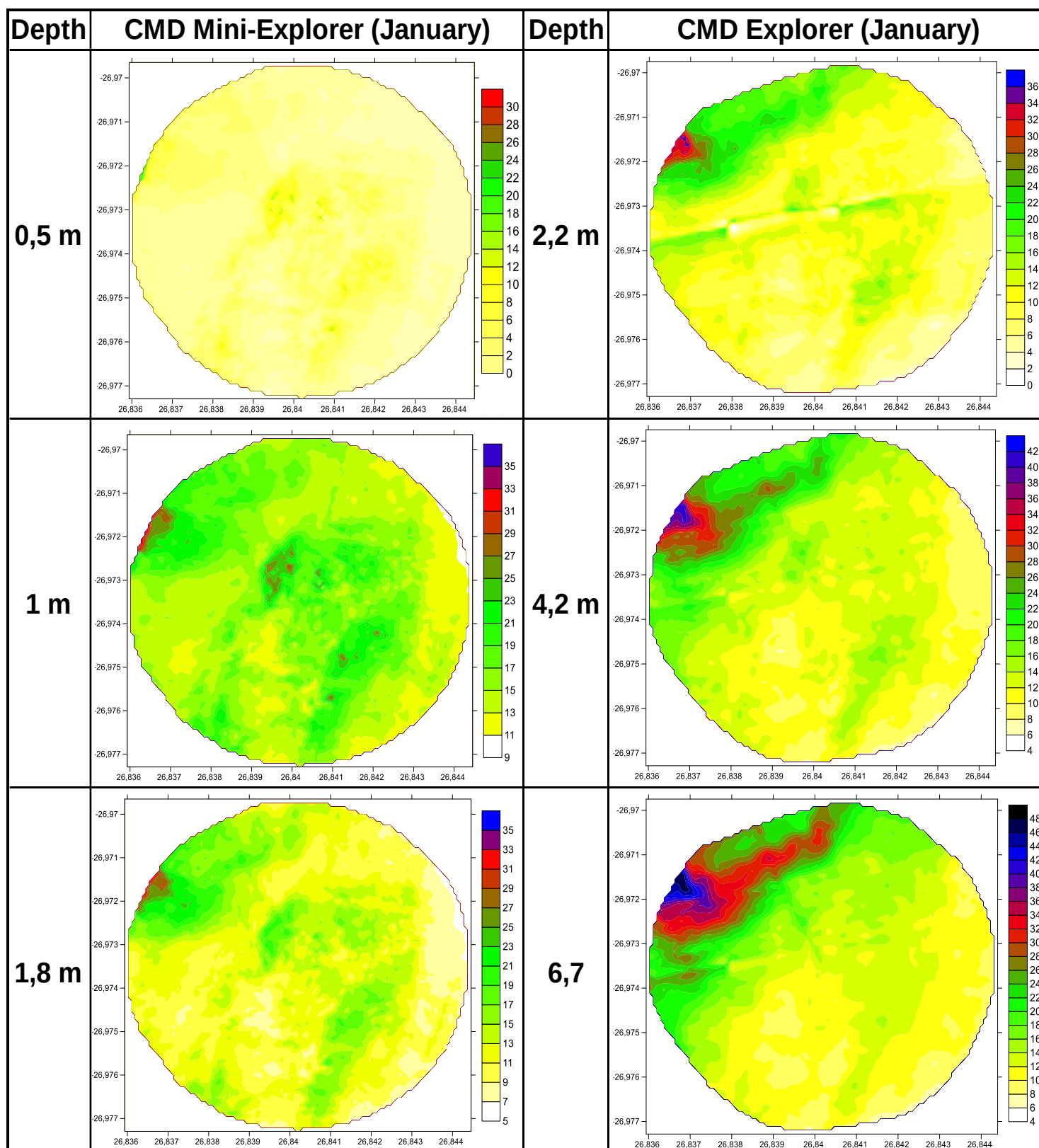


Figure 20: January results of the CMD Mini-Explorer and CMD Explorer. Note that the scales were given in mS/m.

4.2.3.2 *CMD Mini-Explorer and CMD Explorer data for June*

The June data for the CMD Mini-Explorer and CMD Explorer was taken during the dry season, as opposed to the January data that was collected during the wet season. This could clearly be seen in the maps shown in Figure 21, where all measurements taken up to 1.8 metres had much smaller EC measurements (mS/m) compared to that of the January measurements. The CMD Mini-Explorer data for 0.5 metres showed the same three anomalies previously seen, although the magnitude of the anomalies were much smaller due to a decrease in rainfall. Together with the lack of rainfall, the field did not receive any irrigation for the month leading up to June, as the crops planted at the time, were ready for harvesting. At one metre, the first anomaly (to the Northwest) increased in magnitude, together with the second and third anomalies. The same was seen at a depth of 1.8 metres, where the first anomaly had increased, together with the second and third (although these two anomalies had a very slight increase in magnitude). The CMD Explorer data (at 2.2 metres) once again showed a large increase in magnitude, for the first anomaly, with the increase of depth. At 4.2 and 6.7 metres, the first anomaly (to the Northwest) increased dramatically. This shows a large accumulation of water at these depths. The first anomaly once again showed lateral movement of water in a South-westerly direction.

This shows that the North-western part of the pivot is a problem area, and care should be taken when being irrigated. This anomaly (to the Northwest) was present even in the dry season and when irrigation has been stopped. This is the reason for this field having a lower quantity and quality of crop yield experienced by the farmer. Upon further inspection and auger drilling, it was determined that the reason for the second anomaly (in the centre of the field) was due to a leakage of the pipes that lead to the centre pivot. This later caused an accumulation of water on the surface, and could be seen during the drilling for soil samples. The third anomaly (to the Southeast) was determined to be a result of increased clay content in the soil of this area. This was seen to be the case during the mapping of the soil. As a result of this increase in clay content, care should be taken when irrigating this area.

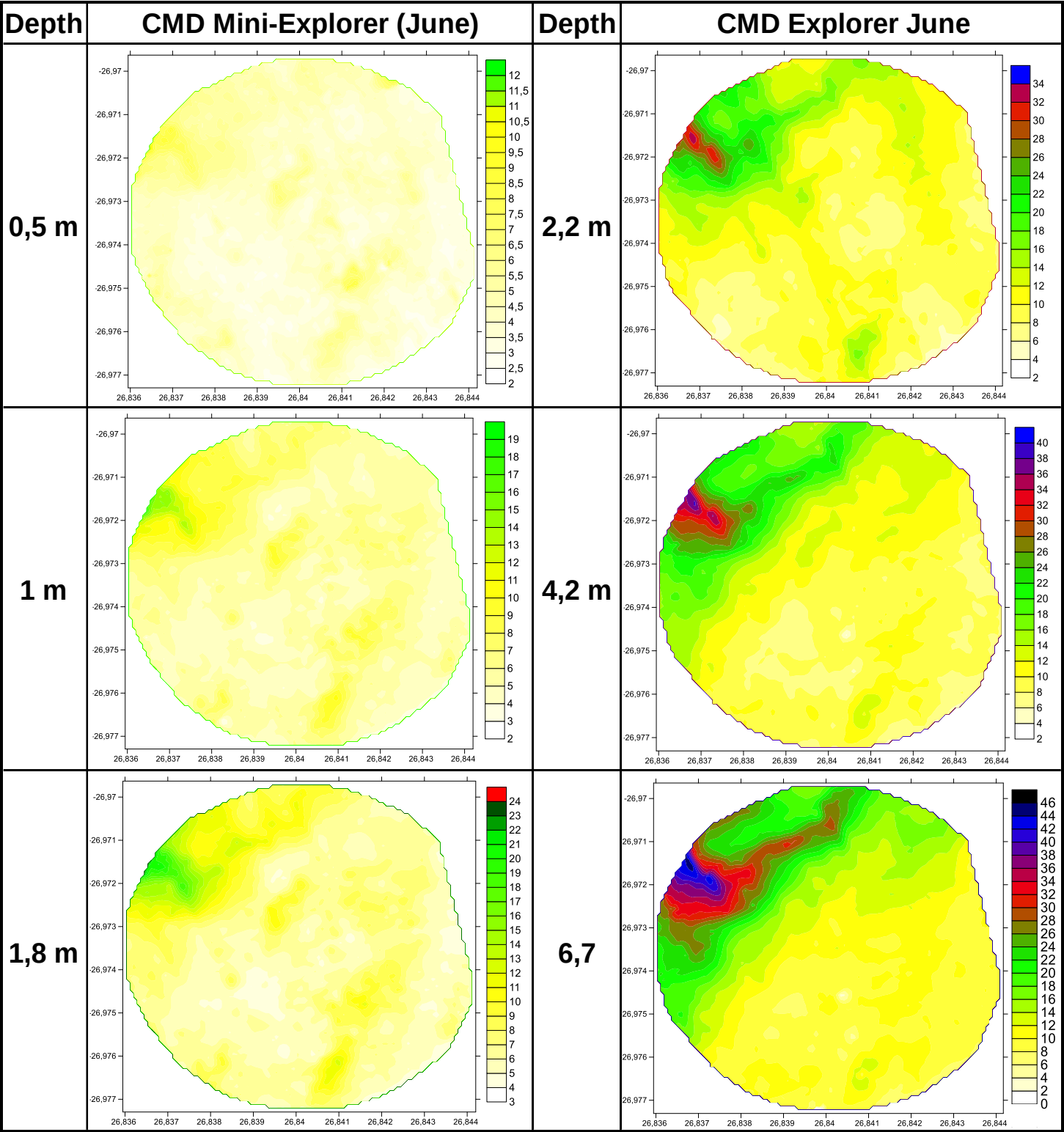


Figure 21: June results for the CMD Mini-Explorer and CMD Explorer. Note that all scales were given in mS/m.

4.2.3.3 *Volumetric, Neutron probe and Diviner data for January*

At a depth of 20 centimetres (in Figure 22), the volumetric- and Neutron probe data showed two anomalies, one in the centre and the other to the Southeast, although the anomalies seen with the Neutron probe data was of lower magnitude. At the same depth, the Diviner data shows one large anomaly to the Southeast. Two anomalies can be seen at 40 centimetres looking at the volumetric data. The first being the anomaly to Northwest, and the second being in the centre and to the Southeast. The anomaly in the centre and to the Southeast (also seen with the Neutron probe data) can be sub-divided into the two anomalies seen with the CMD data, although the interpolation of the volumetric- and Neutron probe data shows it as one anomaly. The Diviner shows three anomalies, where the first anomaly to the Northwest is very small, but still visible. The second and third anomalies are the same as those seen with the CMD data, being at the centre and to the Southeast.

At a depth of 60 centimetres all three anomalies for the volumetric measurements had increased dramatically with an increase of depth. The Neutron probe and Diviner also showed an increase in size and magnitude of the second and third anomaly, with the first anomaly also being present in the Diviner data. These anomalies constantly increased at a depth of 80 centimetres, where the first anomaly at the top left can now also be seen in the Neutron probe dataset. Finally, at 100 centimetres below the surface, the shape and results are slightly distorted, although the first and second anomalies are still present. The first anomaly (to the top left) is absent in the Diviner dataset.

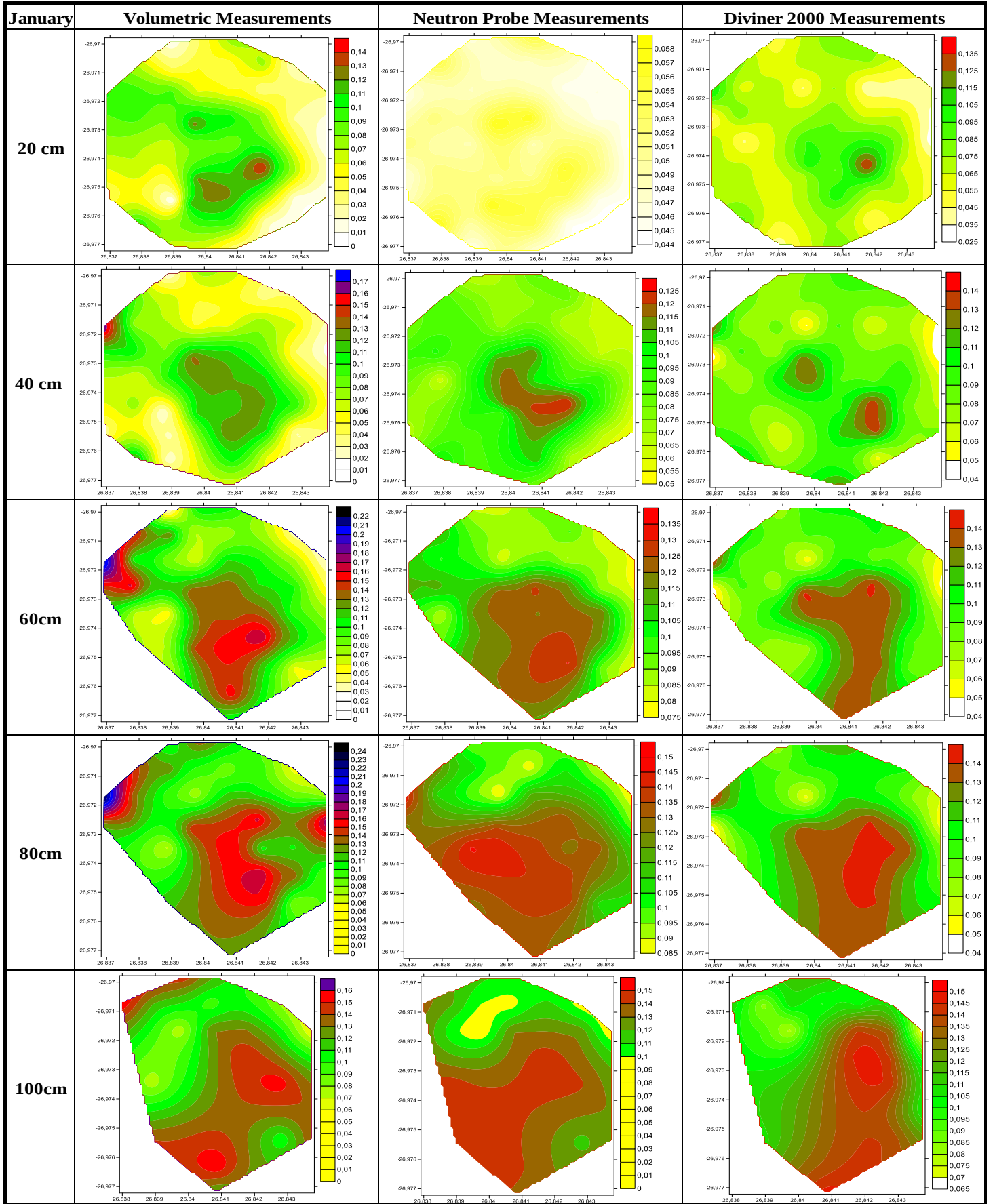


Figure 22: January results for the volumetric, Neutron probe and Diviner measurements.

4.2.3.4 Volumetric, Neutron probe and Diviner data for March

The March volumetric data (at 20 centimetres) presented in Figure 23 showed that, in general, the Western half of the field had a higher SMC than the Eastern half, with two anomalies – one in the centre of the pivot and one to the South. The Neutron probe data had similar results, but the anomalies were less distinct, except for the anomaly in the centre of the pivot. The Diviner data showed that the Northern and Western parts of the field had higher SMC's, with a distinct anomaly to the Southeast. At 40 centimetres, the volumetric data did not show a large increase in SMC, although the two anomalies seen at 20 centimetres have increased in size. At 40 centimetres, the Neutron probe data also showed that the Western half of the field had a higher SMC, with the magnitude and size of the centre anomaly increasing. The Diviner data, as with the volumetric and the Neutron probe data, showed a general SMC increase, with the anomaly in the centre and the anomaly to the Southeast increasing.

At 60 centimetres, all three datasets showed quite a large SMC increase, with the volumetric data showing the largest increase. All three datasets showed an increase in the magnitude of the third anomaly discussed in the CMD datasets, where the clay content of the soil is higher. The volumetric-, Neutron probe- and Diviner data (at 80 centimetres) showed a dramatic increase in magnitude of all three the anomalies. The anomaly in the top left of the field became more evident at a depth of 100 centimetres in all three datasets. The volumetric data showed the largest amount of SMC in the first- and third anomaly. The anomaly, for all the datasets, in the centre of the pivot was not visible at this depth anymore.

The reason for the slightly higher SMC to the West of the field was due to unexpected rainfall during the collection of the data. As seen at a depth of 20 and 40 centimetres, the rainfall occurred during the collection of the data in the Western half of the field. The overall rainfall during March was much less than that experienced in January, as seen with the magnitude of all the anomalies being much smaller. Even with the little amount of rain during March, the anomaly to the Northwest was still present, showing that there is a large accumulation of water in this part of the field.

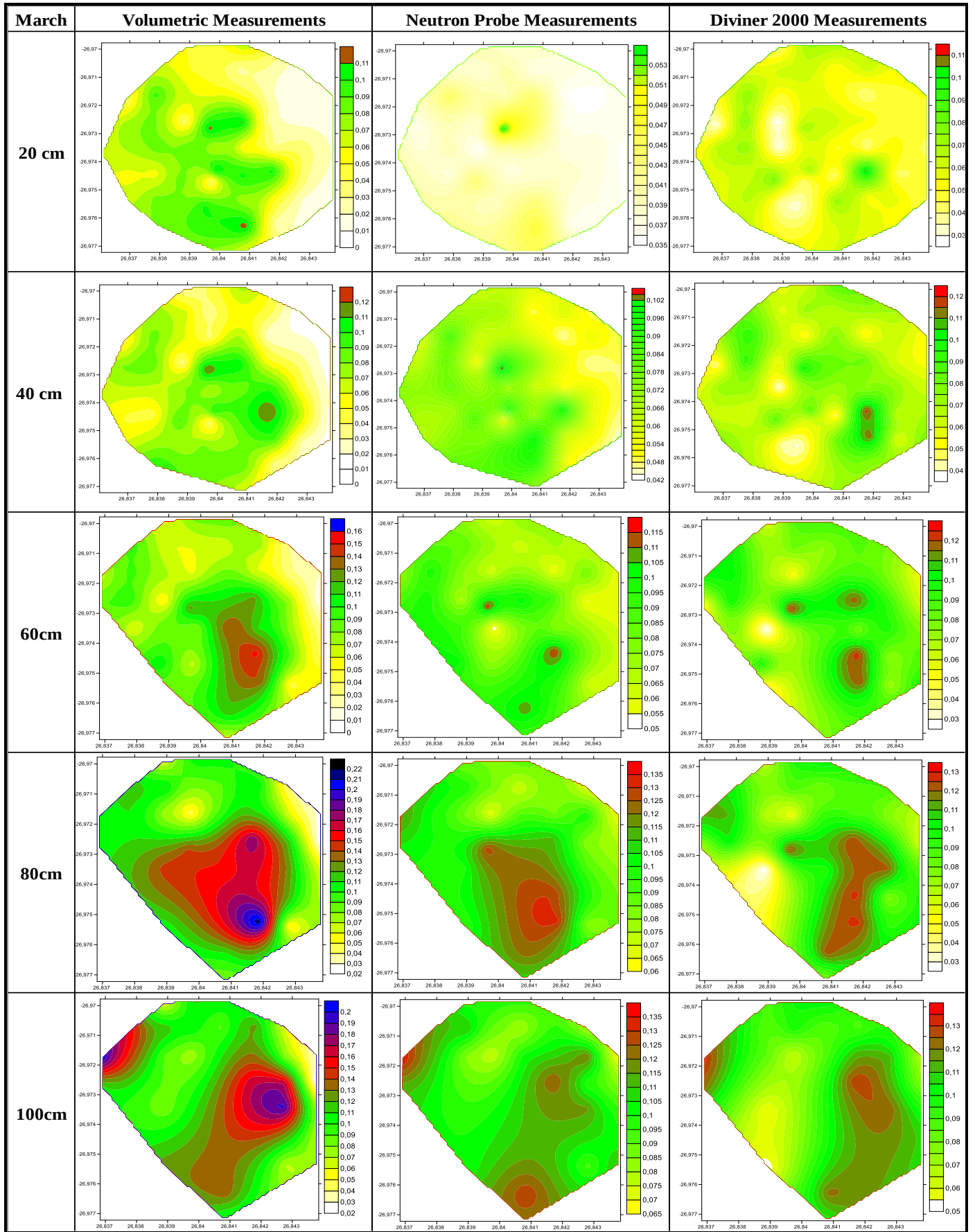


Figure 23: March results for the volumetric-, Neutron probe- and Diviner data.

4.2.3.5 Volumetric, Neutron probe and Diviner data for June

Looking at figure 24 it was clear that, as mentioned previously, the June data was collected during the dry season. This could be seen by the decrease in the overall SMC of the field (considering all three methods) and the magnitude of the anomalies being smaller than the previous two months. At a depth of 20 centimetres, it could be seen that the Western half of the field, once again had a higher overall SMC. In all the June datasets, the first anomaly (in the top left) was present at 20 centimetres, with the second and third anomalies being visible (although very small) in the volumetric and Diviner datasets. As with both the previous months, the Neutron probe data showed less SMC than the volumetric- and Diviner data at the first depth interval. The second and third anomalies became visible at 40 centimetres in the Neutron probe dataset. The first anomaly (for all three datasets) increased in magnitude at a depth of 40 centimetres, with the volumetric data showing the largest increase. In the volumetric-, Neutron probe- and Diviner datasets all three the anomalies had quite a large increase in magnitude at 60 centimetres, with the volumetric dataset showing the largest increase. Due to the amount of data being available from this depth and deeper (≥ 60 centimetres), the third anomaly seems to shift to the South, but if compared to shallower depths it can be seen that this is the third anomaly, as discussed with the CMD datasets, caused by the increase in clay content. The reason for the phenomenon of the anomaly shifting South, was due to the software output, although the geographical location of the anomaly remained the same.

At 80 centimetres, the volumetric- and Neutron probe data showed an increase in the magnitude of all three anomalies, but the Diviner data only showed the first and third anomalies to increase. The first anomaly was still visible in both the volumetric- and Neutron probe datasets, but was not visible in the Diviner dataset at 100 centimetres. Looking at the Diviner dataset, the second anomaly seemed to shift to the right (East), although this anomaly was consistent in the volumetric- and Neutron probe datasets. Lastly, the third anomaly had a large increase in magnitude looking at the Neutron probe- and Diviner datasets, with the Neutron probe showing the largest increase. Looking at the volumetric dataset, the size of the anomaly increased, while the magnitude of the anomaly decreased. Even though the increase in size and magnitude of the third anomaly in the three datasets are not precisely the same, the data suggests that the anomaly caused by the increase of clay content slightly increased up to a depth of 100 centimetres.

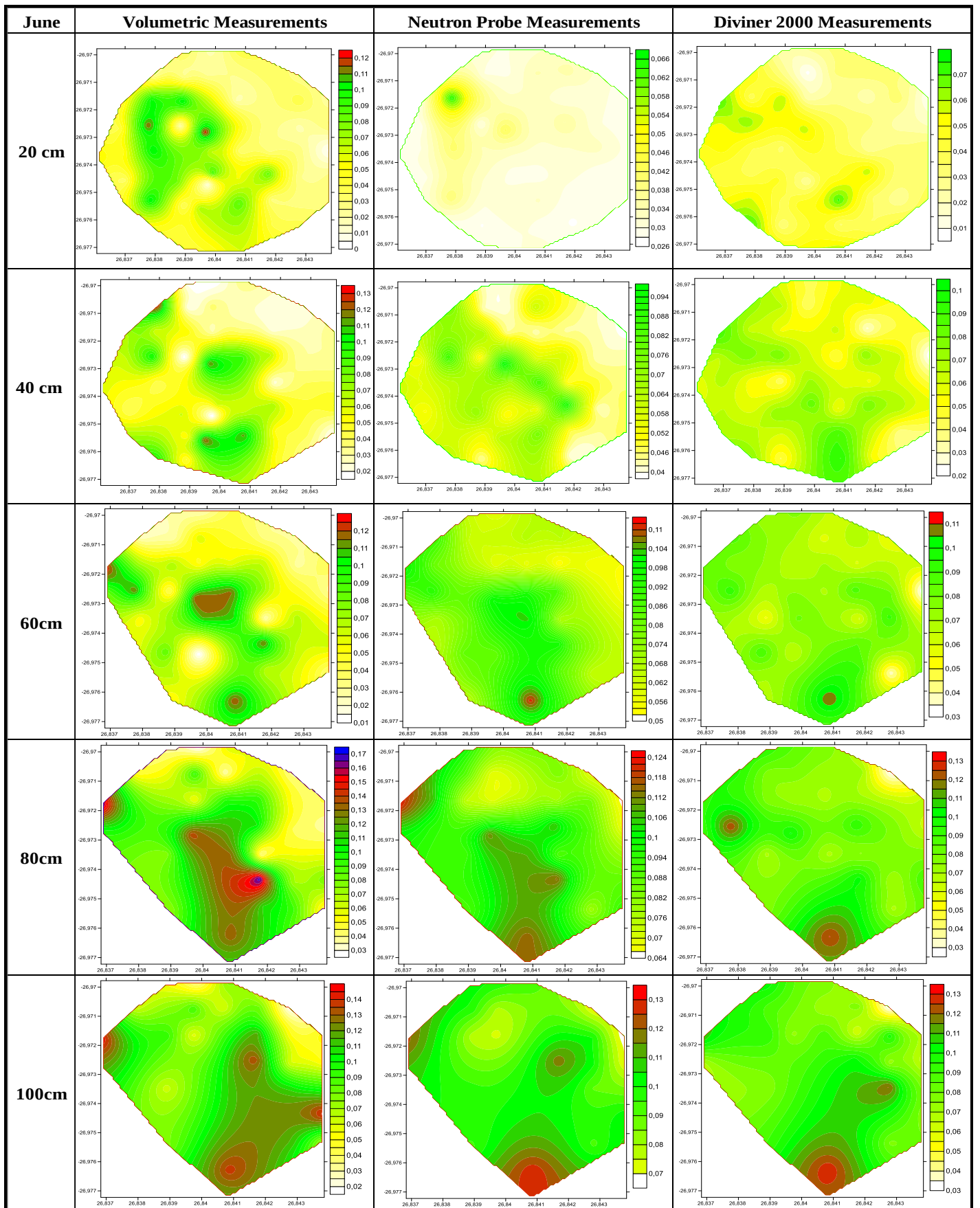


Figure 24: June results for volumetric-, Neutron probe- and Diviner data.

4.2.4 Geology of study area compared to anomaly on Pivot four

After looking at the literature study of the area and comparing the geology to the results found with the geophysical apparatuses, an interesting phenomenon was observed. It was discovered that the large anomaly (discussed as anomaly one, to the Northwest) was clearly located on a different geology, compared to the areas with lower SMC. Figure 25a shows the data for the CMD Explorer, during June, at a depth of 6.7 metres. The anomaly to the Northwest, as discussed previously in this chapter, showed a large accumulation of water at a depth of 6.7 metres and indicated that there are lateral flow of water in a South-westerly direction. This lateral flow of water is due to the topography of the surrounding area.

The geology discussed in Chapter 3 can be seen in Figure 25b, where the Pretoria Group (Transvaal Supergroup) and the Madzaringwe Formation (Karoo Supergroup) were shown. In Figure 25b the Pretoria Group was represented in blue and is located to the West (the left side of the pivot) (Council for Geoscience, 2008). The Pretoria Group, as mentioned in Chapter 2, mostly consists of mudstones, sandstones, andesitic lavas, diamictites, conglomerates and carbonate rocks (Johnson *et al.*, 2006). The geology found in the specific area of study (represented in blue), is mainly basalt (Council for Geoscience, 2008). The Madzaringwe Formation was shown in yellow and can be seen to the East (the right side of the pivot) (Council for Geoscience, 2008). The Madzaringwe Formation, discussed in detail in Chapter 2, mostly consists of shale, sandstone and siltstone (Johnson *et al.*, 2006). According to the Council of Geoscience (2008), the geology of the study area (represented in yellow) consists of siliciclastic rocks of which mainly sandstones are found.

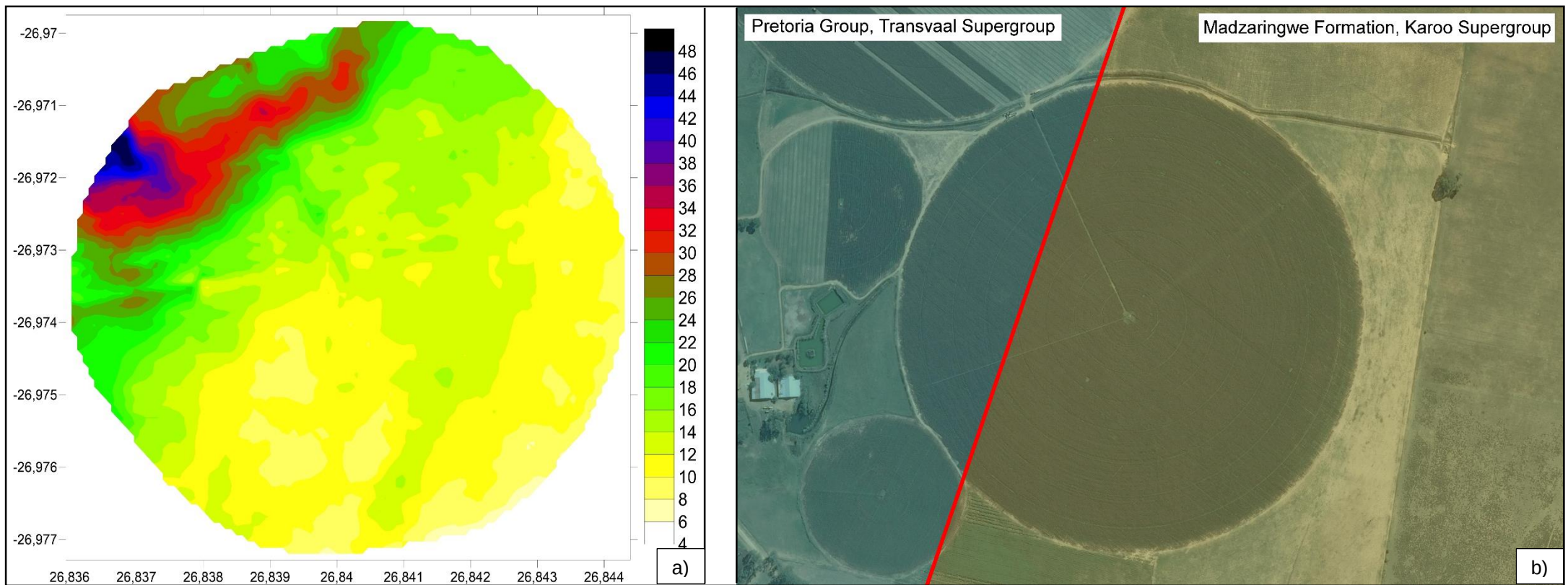


Figure 25: a) January data of the CMD Explorer (at 6.7 metres) showing an anomaly to the Northwest of the pivot. b) Geology of the study area showing the Pretoria Group (Transvaal Supergroup) in blue to the left, and the Madzaringwe Formation (Karoo Supergroup) in yellow to the right. The red line was used to show the contact between the two geologies more clearly (Google Earth, 2016b).

Figure 26 shows the CMD Explorer data (seen in Figure 25a) on top of the geology of the pivot (seen in Figure 25b). The large anomaly seen at a depth of 6.7 metres, was mainly present on the Pretoria Group. Although most of the anomaly is geographically located on the Pretoria Group, a small part stretches over the Madzaringwe Formation. The reason for this is most likely due to the digital geological map used for the representation of this phenomena, which was on a very small scale (1:2 000 000). Maps with such small scales tend to lose detail, and are often described as having a coarse resolution (Quattrochi & Goodchild, 1997; Nagendra, 2001). This could result in the distortion of visually represented data (Quattrochi & Goodchild, 1997; Nagendra, 2001). Another reason for the anomaly in Figure 26 not being completely located on the Pretoria Group, could likely be due the geological map used in this study (on a scale of 1:2 000 000) being based on a 1:1 000 000 map that was originally created in 1997 (Council for Geoscience, 2008). This suggests that if the geology were mapped on a finer scale, the anomaly would have been a good indicator of the two geologies, because the contact between the geologies would likely have looked different (implying that the contact would be rotated a bit clockwise). Although this study area could not necessarily be considered as large enough for a regional representative of the geology, the geological map of South Africa could be revised and data such as this could be used to increase the resolution of the map.

The similar spatial trends between the SMC and the geology could be explained with the hydraulic conductivity of the basalt and sandstone found in this area. Figure 26 shows that areas with higher SMC are located on the Pretoria Group, and areas with lower SMC are seen on the Madzaringwe Formation. Looking at the hydraulic conductivity (K) of the two predominant rocks in the specific study area, basalt has a large range of K which varies from 1×10^{-8} to 1×10^4 metres per day (Anderson *et al.*, 1999; Heath, 1983). The K of basalt varies depending on whether the rock is fractured or not (and the severity of fracturing), the physical characteristics of the basalt (like the type of lava flow) and whether other geological units are present (such as dikes intersecting the basalt flow) (Anderson *et al.*, 1999; Heath, 1983). The K of sandstone varies from 1×10^{-5} to 1 metre per day (Boving & Grathwohl, 2001; Heath, 1983). The K in sandstones are affected by the fracturing of the rock, the grain sizes, grain arraignment and the cementation of the grains (Boving & Grathwohl, 2001; Heath, 1983).

This shows that basalt could either have a much smaller K than sandstone, or much higher. The specific K for basalts, as well as sandstones, varies from study to study, depending on the factors mentioned and what methods were used to test K . The K values mentioned earlier were based on three studies that used similar methods of determining K for basalts and sandstones. Considering these K values, it is clear that the basalts present in the Pretoria Group (in this specific area of study) has a much smaller K than the sandstones from the

Madzaringwe Formation. This shows that the basalts are much less permeable. The opposite is true for the sandstones, where water permeates through the sandstones much quicker. This leads to an accumulation of water on the basalts, possibly at greater depths than those measured in this study.

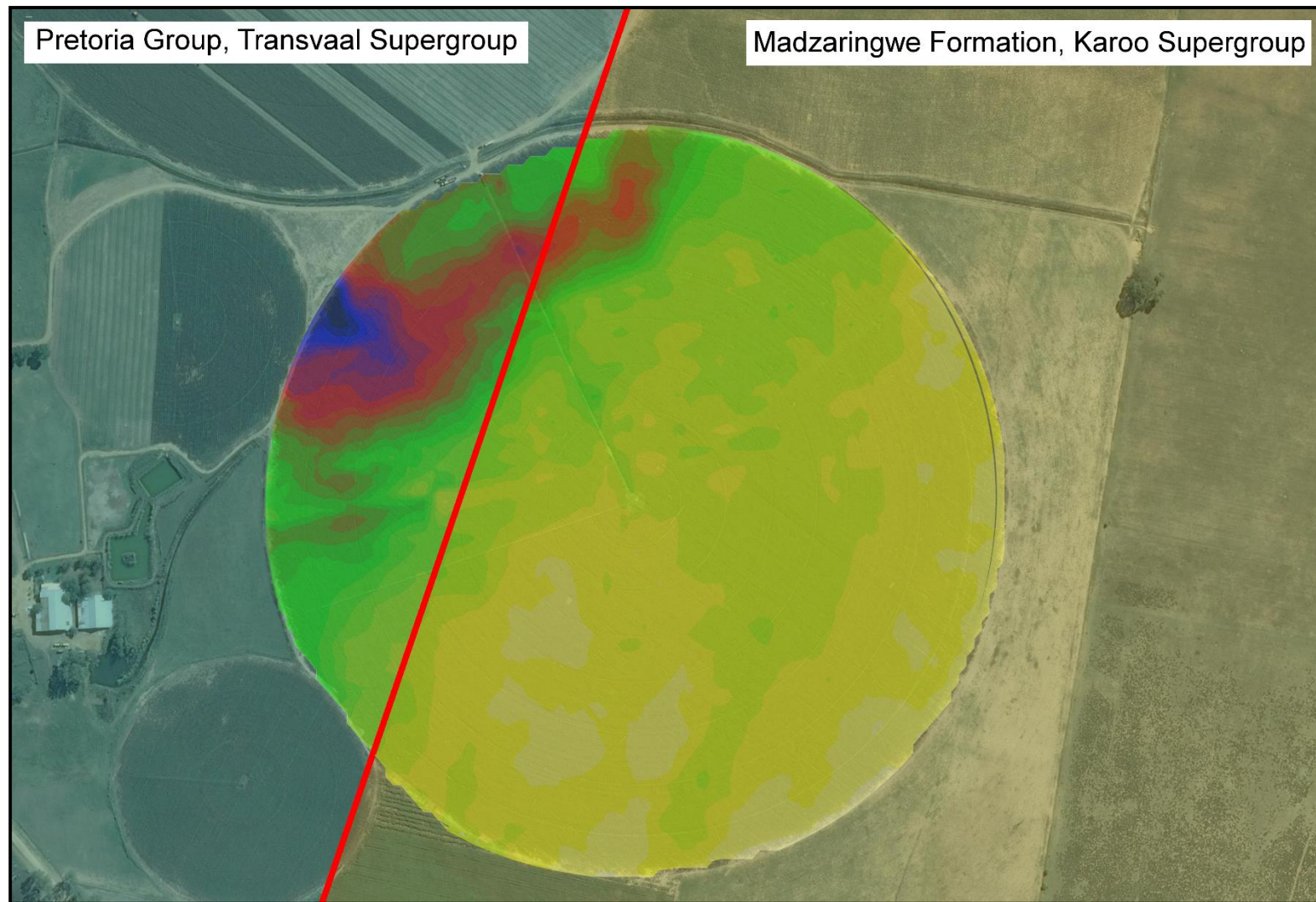


Figure 26: The January CMD Explorer data (at 6.7 metres) are shown together with the geology of the study area. The Pretoria Group is shown in blue and the Madzaringwe Formation is shown in yellow (Google Earth, 2016b).

4.2.5 General discussion

It should be noted, that the measurements taken during the month of January was during the wet season, and high amounts of rain was experienced on the farm during the months of December 2017 and January 2018. This was quite evident when looking at the CMD-, volumetric-, Neutron probe- and Diviner data. All the apparatuses recorded higher amounts of SMC during this month, than those compared to the March and June datasets. The rainfall that occurred during the data collection for the month of March, could clearly be seen when looking at the volumetric-, Neutron probe- and Diviner data. Referring to Figure 23, it could be seen that the measurements taken before the rainfall was in the East, as the SMC was higher in the Western half of the field (seen as the measurements taken in the Western half were during or after the rainfall event). Although the Western half of the pivot, generally had higher SMC, the March dataset showed a slightly larger SMC difference in the two halves of the field.

It is clear that there were three main areas of concern on this pivot. The first area being the anomaly to the Northwest (top left), where it was clear that there was an increase of water accumulation with an increase of depth. This is a natural occurrence caused by the geology and topography of the study area. The reason being that the topography had a general slope towards the river, and the subsurface water would naturally flow with the gradient towards the direction of the river. It was also noticed that at the depth of 2.2 metres and deeper, lateral flow of water occurred in a South-westerly direction, generally following the topography towards the river. The second problematic area was in the centre of the pivot, where large amounts of water accumulated on the surface and up to a depth of one metre. With the aid of the CMD, it was discovered that there was a leakage of the pipe leading to the centre pivot. This results in a couple of concerns, the first being that a large amount of water is being wasted. This is a critical concern, because as mentioned, South Africa is a water scarce country and this could lead to environmental concerns (such as surface erosion, nutrient loss due to leaching, influencing the habitats and activities of microorganisms, as well as the overall degradation of the soil and the quality thereof). The second major concern is that crops will struggle to establish and grow in this area, as there is an excess amount of water and this could decrease the crop quality and –quantity. The third problem area was the third anomaly (to the Southeast), caused by an increase of clay content. This does not only decrease the infiltration rate of water, but the higher clay content also causes the soil to become saturated much quicker (due to the swelling properties of the clays), and to stay saturated for a longer period of time, than other areas of the pivot.

To mitigate the effects of over saturation at the first and third anomalies, more care should be taken when these areas are irrigated. This could be done manually, where the intensity of the irrigation sprayers could be decreased (decrease the amount of water) or the speed of the

pivot could be increased over these areas. Although, the manual control of irrigation systems are not really viable for large scale farming or other large scale irrigation projects (such as mine rehabilitation). The reason being that it would be very time consuming to constantly tend to the specific conditions of irrigation required. Another possibility is to use other technological methods such as drip irrigation systems or precision farming methods where a computer-guided system is used to regulate water flow and movement speed of the pivot. These computer-guided systems could also be used in conjunction with coordinates, which could be updated periodically (e.g. seasonally) with data acquired with apparatuses such as the CMD and Diviner. The updated SMC of the coordinates (over extended periods of time) would thus provide better accuracy of the problematic areas as time progresses and could aid in the long-term management of these areas. While these methods could greatly increase crop quantity and -quality, as well as assisting with the management of these problematic areas, it was beyond the scope of this study to go into further detail on this subject and further research is recommended for future studies.

Considering the statistical results, it was clear that there were good statistical probabilities that the methods and apparatuses used would yield similar results. The Null hypotheses were accepted for the T-test and ANOVA analyses between the volumetric-, Neutron probe- and Diviner datasets. The ANOVA analyses where the CMD data was included in the volumetric-, Neutron probe- and Diviner datasets, resulted in poor probability for similar results – this suggested that the CMD data would not yield similar results compared to the other three datasets at all. This was attributed to the fact that the volumetric- and calibrated volumetric measurements were used for the all methods except the CMD. The CMD gave EC measurements (mS/m), which was not calibrated as SMC measurements. The reason for this was to see if there would be similarities in the data of the raw CMD measurements and the calibrated volumetric measurements of the other apparatuses. This was done to find out if the CMD could be used to produce reliable SMC data without using it in conjunction with other SMC measuring devices, while taking possible environmental pollution such as high amounts of salts and metals in to consideration (this was done as part of the third aim of this study). The purpose of using the calibrated volumetric SMC measurements (as opposed to the raw data) for the Neutron probe, was due to the raw measurements given in counts – which is not a usable format for volumetric SMC. The raw Diviner measurements can be used as an indication of soil moisture increases or decreases over time (which is done by using the graph feature on the control unit). Although an indication of soil moisture increase or decrease over time can be applicable in certain cases (such as pivot irrigation management), it does not provide volumetric SMC measurements. To measure the volumetric SMC, a calibration of the SF measurements need to be done. Although the ANOVA analyses suggested that,

statistically, there would be no probability of the CMD having similar results to the other apparatuses, the visual results showed that there were indeed similar spatial trends. These results suggest that the CMD could be used as a good indication of SMC, if a proper study of the area is conducted to determine possible influencing factors and variables such as pollutants or ore bodies.

In general, the first depth (20 centimetres) of the Neutron probe data showed much less SMC than the volumetric- and Diviner data. This was most likely due to a common phenomenon experienced by the Neutron probe at shallow depths (Evelt et al., 2003; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001). The phenomenon is referred to as atmospheric interference, which is a result of the probe's sphere of influence extending above ground (Evelt et al., 2003; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001). This then causes neutrons to be lost into the atmosphere, or it could affect the interaction of neutrons with the surrounding soil (Evelt et al., 2003; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001). The above-mentioned suggests that the measurements taken by the Neutron probe at depths of 20 centimetres or less, are likely to be less reliable as compared to the volumetric- and Diviner data (Evelt et al., 2003; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001). Although this phenomenon was seen very clearly in all the visual representations (as well as being mentioned in other literature) some of the anomalies were still visible, but the magnitude of the anomalies were much smaller compared to the other datasets (Evelt et al., 2003; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001). Thus, suggesting that the Neutron probe would not be the preferred method of shallow SMC investigation if high accuracy measurements are needed (Evelt et al., 2003; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001). The Diviner on the other hand, showed similar results to the volumetric measurements at shallow depths (≤ 20 centimetres) and would therefore be considered as the preferred method of shallow SMC investigations. When SMC measurements of depths deeper than 20 centimetres are required, both the Neutron probe and the Diviner are possible methods to consider. When considering investigations for depths of more than 1.6 metres, the Neutron probe is a better option for the geophysical investigation of SMC. This is due to the physical limitations of the Diviner only being able to take measurements up to 1.6 metres, and the Neutron probe which could be used for measurements of up to 20 metres below ground (as in the case of the model used in this study).

Another limiting factor experienced during this study, was the constrictive layer encountered when drilling holes and collecting samples with the hand auger (most often at depths of one metre or deeper). This not only limited the depths of the holes drilled, but also the amount of data collected for the volumetric-, Neutron probe- and Diviner measurements. With the soil mapping, on the other hand, this restrictive layer did not affect the soil sampling and data

gathering, as a hydraulic drill was used. Furthermore, this constrictive layer (hypothesised to be a palaeochannel) was thought to be a contributing factor to the water accumulation occurring at a depth of one metre and deeper, discussed as the first anomaly in the CMD results. In Figures 20 and 21, this phenomenon was observed where the second and third anomalies increased in magnitude up until a depth of one metre, and thereafter decreased with an increase of depth. Whereas the magnitude of the first anomaly only increased with the increase of depth, likely caused by the accumulation of water at depths deeper than 6.7 metres (which was the maximum depth measured).

Considering the results discussed, data collection, data management, data processing, the resolution of the results, experiences of the apparatuses in the field and the time and labour needed for all the different apparatuses, the CMD was considered as the overall best method for geophysical investigation of indicating SMC (if the proper steps were taken to include possible environmental factors and variables). Using the CMD for investigations (in this case for SMC measurements) has advantages and disadvantages. The advantages are that the apparatus is set up within minutes, it does not require manual calibration (if EC measurements are going to be used), it is very labour- and time efficient, the data is transferred and managed very easily and lastly, the high resolution of the results. The biggest disadvantage of the CMD is the cost of renting or acquiring the apparatus, as well as the cost of insuring it. An important disadvantage to consider in the case of studying SMC, is that the raw measurements are given in mS/m and not as a direct measurement of volumetric soil moisture (referring to the fact that a calibration protocol would be needed to calibrate the SMC measurements). Another disadvantage, although being minor, is the need for additional software (as mentioned in Chapter 3). Therefore, the CMD would be a good long-term investment for industrial- (e.g. construction), consulting- (e.g. project based investigations) and large-scale commercial use (e.g. large scale precision farming).

For farming, personal and other smaller scale uses or investigations, the Diviner would be the most effective and efficient method for SMC measuring. As with the CMD, the Diviner also has certain advantages and disadvantages. Advantages of the Diviner is firstly, that this is a small and lightweight apparatus, as well as being the cheapest to acquire (as compared to the CMD and the Neutron probe). Secondly, after the initial cost and labour of installing the access tubes, the Diviner was the most cost-, time- and labour efficient method – as it would be possible to measure the SMC of the 56-hectare pivot in one day with pre-installed access tubes. Thirdly, the Diviner poses no concern to the health of humans or the environment. The reason being that the Diviner is based on the FDR method and makes use of the soils' dielectric constant, unlike the Neutron probe that contains a nuclear source (and is based on the neutron scattering method). Not only is the Neutron probe a source of radiation, but it

requires annual calibration by a professional and this results in unnecessary annual expenses. The Diviner does not need constant calibration and the calibration could be done by anyone, when following the simple steps set out by the user guide. The largest disadvantage of the Diviner is the data transfer and -management. The Diviner stores the data in a format which is not readably useable for other software (e.g. for *Microsoft Excel*) and should first be converted by software designed for the Diviner 2000 (as mentioned in Chapter 3).

The Diviner itself is easily calibrated in the field, but if the consumer requires calibrated volumetric data, the supplier or a consultant would initially be needed to do a statistical calibration of the Diviner data with volumetric measurements. After the initial statistical calibration of the Diviner data with the volumetric measurements, the data collected thereafter could very easily be calibrated by the consumer. This could be done by using the pre-existing methods and software used for the initial calibration. Even if the consumer is not willing to do the statistical volumetric calibrations or it is not required, the SF measurements taken by the Diviner would be sufficient in small scale investigations (such as day to day irrigation scheduling). The SF measurements, in the case of a day to day irrigation schedule, could be considered as a relative measurement of SMC. The control unit of the Diviner 2000 has the capability of displaying the captured data (SF measurements) on a line graph. Which indicates the relative increase or decrease of SMC, and this could be used as a general guideline for irrigation.

The Neutron probe is, however, not completely disregarded in this study. An advantage of using the neutron scattering method, is that this method is well-known, trusted and an accurate way of measuring SMC, and has been since about the 1950's (Evelt et al., 2003; Fayer & Gee, 2005; Robock, 2015; Smith & Mullins, 2001). Disadvantages of the Neutron probe (like the CPN 501DR Depthprobe model used in this study), includes that it is a heavy, complicated and time-consuming apparatus to use. An example is the complexity and difficulty at which this apparatus is calibrated in-field for soil bulk density and SMC (Evelt et al., 2003; Schmugge et al., 1980; Smith & Mullins, 2001). There are also precautions associated with storage, handling and transport, which is due to the radioactive nature of this apparatus (Evelt et al., 2003; Fayer & Gee, 2005; Robock, 2015; Schmugge et al., 1980; Smith & Mullins, 2001).

The conclusion being that the CMD is the preferred apparatus for industrial, consulting and large-scale commercial use, and the Diviner 2000 is the preferred apparatus for farming, personal and other smaller scale uses or investigations. The Neutron probe (although being a well-known, trusted and accurate method) is not considered as a time- and labour efficient method, based on the disadvantages discussed previously. The CMD and Diviner are both considered to be easier, quicker and labour efficient methods of SMC investigation, as

compared to the traditional oven drying method (for gravimetric and volumetric measurements) and the Neutron probe.

CHAPTER 5: CONCLUSIONS

5.1 INTRODUCTION

This chapter serves as conclusion for the study, giving a summary of the background, introduction, geophysical methods used, the methodology followed throughout the entire study and the results found. Lastly, the recommendations for further research is given, where improvements and other methods of investigation is suggested.

5.2 CONCLUSION

5.2.1 Conceptualisation of the Project

Water scarcity is increasing worldwide, and is quickly becoming an international concern. There are multiple reasons leading to water scarcity, such as rapid population growth, urbanisation and the continued improvement of living standards. In Southern Africa, drought is a common and recurring phenomenon. The variable interannual amount of rainfall in South Africa puts large amounts of stress on crop- and livestock farming in the country. With this, there are two main classifications of droughts, the first being an agricultural drought and the second a hydrological drought. The drought is classified by the duration thereof, where an agricultural drought is between three and six months, and a hydrological drought lasts one year or longer. SMC greatly influences plant growth and nutrient transport in soil, and crop production is especially dependent on the SMC. For this reason, the constant measurement of SMC plays a very large role in successful crop production.

Very simply put, geophysics is a science that relies on physics and other physical properties to investigate the Earth. Geophysics makes it possible to accurately describe the interior of the Earth, through the collection of data and the distribution thereof. The term geophysics can generally be used to describe a range of measurements taken for various uses. In the field of geology, soil science and hydrology, the term '*Applied geophysics*' is used, and generally implies that the investigations are conducted at 100 metres or shallower. The field of applied geophysics is a large network of interconnected disciplines, with three main sub-disciplines being exploration-, engineering- and environmental geophysics. Geophysics makes it possible to do both invasive and non-invasive studies, depending on the circumstances. In this study, both these methods were utilised to investigate SMC.

It was hypothesised that the CMD Mini-Explorer-, CMD Explorer-, volumetric-, Neutron probe- and Diviner measurements would have a positive statistical probability in terms of producing

similar and reliable SMC measurements. It was further hypothesised that the Diviner 2000 would be the most appropriate method for continuous, long-term SMC management, in terms of cost- and time efficiency.

The aims and objectives of this study were, firstly, to determine whether there were statistical and visual similarities between the different methods and apparatuses used in this study. Secondly, to locate and discuss areas of concern on the pivot under investigation. Finally, to determine which apparatus would be best suited for different situations by considering the cost- and labour efficiency of each apparatus.

5.2.2 Literature Review

The CMD is an apparatus that is mainly used for geological and environmental studies and operates as an EM technique. Over the last few decades, the popularity of EM methods, for the use of geophysical investigations, have increased. The main reason for this is the non-invasive nature of this method, together with it being very time- and labour effective. This method has the advantage of taking very high-resolution measurements, with the disadvantage of having set depths at which it operates. This apparatus operates at 30 kHz and is therefore defined as a VLF EM method. This device can be set to measure at two sets of defined depths, and is done by setting it up in either the HCP- or VCP orientation. Another reason that this apparatus is gaining popularity over Earth resistance methods, is the fact that the same volume of Earth material is measured for any point sampled. This adds to the accuracy of the apparatus, as it eliminates variables such as varying volumes of soil measured. Note that for the purpose of this study, only the HCP orientation was utilised for taking measurements. Measurements were taken at 0.5, one, 1.8, 2.2, 4.2 and 6.7 metres below the surface of the Earth.

The Neutron probe, initially developed in 1950, is a nuclear technique used to measure SMC and soil density. The SMC is measured indirectly by means of the neutron scattering method, which is estimated by means of thermal or slow neutron density. The Neutron probe measures SMC by means of an Americium-241:Beryllium core, and measures soil density with a Caesium-137 core. This is an invasive measurement technique, where an access tube is installed in the ground, and the probe is lowered to the desired depth, where a reading is then taken. The access tube needs to be sealed at the bottom, as to ensure that moisture does not enter from the bottom. For this study, 20 centimetre intervals were used to collect the data. A Count Ratio of 16 seconds were used to measure SMC, and this was found to be sufficient. For the density measurements, a 32 second count interval was used.

The use of FDR for the purpose of indirect SMC measuring, has increased over the last decade. This is mainly due to the fact that these methods are easier to use and is generally less destructive. The Diviner 2000 is a product produced by Sentek Propriety Limited, and is a portable and lightweight SMC monitoring device. FDR is used to measure the dielectric constant of the soil, where the soil acts as a capacitor when placed between the two electric plates. With this method, the soil is included as part of the capacitor, where the permanent dipoles of water become aligned and polarised by the electric field. Devices using this method is also referred to as capacitance probes. The Diviner takes automatic SMC measurements at 10 centimetre intervals and also logs the data automatically on the handheld monitor. This data can then be extracted, and used at a later stage.

5.2.3 Materials and Methods

The study area is located roughly 50 kilometres Southwest of Potchefstroom and roughly 40 kilometres Southeast of Klerksdorp. The farm is located in the Free State Province, and is adjacent to the Vaal River, which borders the North West Province. The climate of the study area is that of a typical South African Highveld, with average maximum summer temperatures of 29 °C and average minimum summer temperatures of 14 °C. The average maximum- and average minimum winter temperatures are 21 °C and 3 °C respectively. This area has an average precipitation of 490 millilitres per year. The five soil formations found on the pivot is Avalon, Constantia, Longlands, Wasbank and Westleigh, and has a total area of 56 hectares. The study area is mainly underlain by the Transvaal Supergroup (Pretoria Group) to the North and West, and the Karoo Supergroup (Madzaringwe Formation) to the South and East. The grid system used for the CMD Explorer was a 20 by 20 metre grid, whereas the grid used for the CMD Mini-Explorer was a 10 by 10 metre grid. The data collection for the volumetric-, Neutron probe- and Diviner- data was done on a 100 by 100 metre grid

The CMD Mini-Explorer and CMD Explorer had very similar setup procedures, where the only difference in setup was the CMD Mini-Explorer being mounted on a sleigh. Care was taken to ensure that both the apparatuses were correctly setup in the HCP orientation. The CMD Mini-Explorer was set to automatically take measurements and GPS coordinates every 0.5 seconds and the CMD Explorer every second. The data were analysed by using *Surfer 11*, *ArcGIS 10.3* and *Microsoft Excel*.

For the volumetric data collection, a hand auger was used to drill holes. Samples were taken at every 20 centimetre interval, the samples were then put in plastic zip seal bags and marked. These samples were then placed in an airtight container, as to minimise the gain or loss of moisture. The gravimetric- and volumetric water contents were then tested at the lab within 24

hours of the samples being collected. After all the data has been collected, the gravimetric water contents were then used to determine the volumetric water contents. This was done by taking the gravimetric measurements and multiplying the data with the calibrated density measurements taken by the Neutron probe.

For the Neutron probe, no prior- or in-field calibrations were necessary. After the holes had been drilled for the gravimetric and volumetric samples, PVC access tubes were installed into the ground. The recorded measurements were taken every 20 centimetres. This was done for both the SMC- and density measurements. For the calibration of the density measurements, a calibration protocol was setup to calibrate the absolute density measurements. The measurements taken in the field were then calibrated with the measurements taken for the calibration protocol, by means of creating a polynomial trend line and deriving an equation. This equation was then used to calculate the absolute densities. The volumetric calibration was done in similar fashion, where the volumetric- and Neutron probe measurements were plotted against each other on a scatterplot. A straight-line regression was then used to derive an equation for each month. This equation was then used to calibrate the Neutron probe counts to the calibrated volumetric measurements.

The same access tubes used for the Neutron probe was used for the Diviner. The Diviner required an initial field calibration protocol, where the air- and water counts were calibrated by using the standard protocol set by the user guide. The Diviner was set to automatically take readings at every 10 centimetre interval, where the data was then logged on the control unit. This data could then be extracted from the control unit at a later stage, where it was converted to a useable format. For the data analysis, the SF measurements were used to calibrate the volumetric measurements. The data was calibrated exactly the same as with the Neutron probe, where the SF counts were plotted against the volumetric measurements on a scatterplot. A straight-line regression was then used to determine the calibration equation. The SF counts were then calibrated using this equation.

For the statistical analysis of all the data, T-test- and ANOVA analyses were done. A T-test analysis was done for each month, where each of the methods (volumetric, Neutron probe and Diviner) were analysed against each other. For all the T-test analyses, a two-sample T-test was done assuming unequal variance. ANOVA analyses were also done for each month, where all three the methods (volumetric, Neutron probe and Diviner) were analysed in a single factor ANOVA analysis. A second set of ANOVA analyses were done, for January and June, which included the CMD datasets with the other volumetric-, Neutron probe- and Diviner datasets.

5.2.4 Results and Discussion

The first aim of this study was to compare the different geophysical apparatuses and methods with each other (both statistically and visually), to determine whether or not there would be similarities in the data and results. Table 17 serves as a summary of all the T-test analyses done for January, March and June. In Table 17, only the key results were given, which was the T-stat, one-tail p-value, one-tail T-crit, two-tail p-value and two-tail T-crit values. This was given for all three tests done on the volumetric-Neutron probe, volumetric-Diviner and Neutron probe -volumetric datasets. For both the T-test and ANOVA analyses, a standard α value of 0.05 was used. For all the analyses, the null hypothesis was: $H_0: \mu_1 = \mu_2$. The alternative hypothesis was defined as $H_1: \mu_1 \neq \mu_2$.

For all the T-test analyses done in January, March and June between the three datasets (volumetric, Neutron probe and Diviner), the Null hypothesis (H_0) was accepted. In every case, both the one-tail and two-tail p-values were larger than the α value, set at 0.05. In all the T-test analyses, the T-stat values were smaller than the one- and two-tail T-crit values. This substantiates the claim that all these datasets had a statistical probability of yielding similar results. This shows that the Neutron probe and the Diviner could both be used independently for SMC monitoring, and the results would be accepted as accurate.

Table 17: Summary of all T-tests analyses done for January, March and June. Where the volumetric-Neutron probe, volumetric-Diviner and Neutron probe-Diver datasets were shown. Here, only the T-stat, one-tail p-value, one-tail T-crit, Two-tail p-value and two-tail T-crit values were given.

	January			March			June		
	Vol-Probe	Vol-Div	Probe-Div	Vol-Probe	Vol-Div	Probe-Div	Vol-Probe	Vol-Div	Probe-Div
T-stat	0.08	0.31	0.28	0.77	0.46	-0.42	-0.39	0.11	0.61
p-value one-tail	0.47	0.38	0.39	0.22	0.32	0.34	0.35	0.46	0.27
T-crit one-tail	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
p-value two-tail	0.94	0.76	0.78	0.44	0.65	0.67	0.70	0.92	0.54
T-crit two-tail	1.97	1.97	1.97	1.97	1.97	1.96	1.97	1.97	1.96

As with the T-test analyses, the Null hypothesis (H_0) was accepted for the January, March and June ANOVA analyses (which excluded the CMD datasets). The first set of ANOVA analyses again showed that, statistically, there were a high probability of giving the same results, should

these apparatuses have been used separately. The p-values were larger than the α value in each case, and the F-stat values were smaller than the F-crit values for all three months (see Table 18). Thus, as mentioned, both the Neutron probe and the Diviner could be used for SMC monitoring and the results would be accepted as correct.

Table 18: Summary of the ANOVA analyses done for January, March and June, excluding the CMD datasets. This table only shows the p-values, F-stat values and the F-crit values.

	January	March	June
p-value	0.95	0.7	0.86
F-stat	0.06	0.35	0.16
F-crit	3.01	3.01	3.01

When the CMD datasets were included, both the January and June ANOVA analyses (in Table 19) had p-values of zero and in both cases the F-stat values were significantly higher than the F-crit values. This showed that, statistically, there was no probability of having similar results between the datasets when the CMD data was included with the volumetric-, Neutron probe- and Diviner data. In both these cases, H_1 was accepted and H_0 was rejected. The reason for this was due to the different outputs of the data for the CMD Mini-Explorer, CMD Explorer, volumetric, Neutron probe, Diviner. The volumetric-, Neutron probe- and Diviner data was used as volumetric- and calibrated volumetric water content and the CMD datasets were used as EC (mS/m).

Table 19: Summary of the ANOVA analyses done for January and June, including the CMD datasets. This table only shows the p-values, F-stat values and the F-crit values.

	January	June
p-value	0	0
F-stat	837.75	823.02
F-crit	2.38	2.38

Together with the first aim of the study (in this case finding visual similarities between datasets), the second aim of the study was to find and discuss problematic areas on the pivot. The objective was to locate these problematic areas by analysing the anomalies and discussing them in detail. The visual results of the CMD Mini-Explorer and CMD Explorer showed three very distinct anomalies. The first of which was to the Northwest, the second being in the centre of the pivot, and the third anomaly can be seen in the Southeast of the pivot. During January and June (looking at the CMD data), all three anomalies increased in magnitude up until one metre below ground. At 1.8 metres, the second and third anomalies

were seen to decrease in size and magnitude. This indicates that there is an accumulation of water between one and 1.8 metres below ground. This phenomenon was due to the restrictive layer encountered during this study. This restrictive layer is thought to be a palaeochannel, and this layer causes the water to accumulate on top of it and not allowing water to infiltrate further. With an increase in depth, the first anomaly greatly increases in magnitude and size. The reason being that water possibly accumulates at a depth of more than 6.7 metres. At 6.7 metres, the results showed that lateral flow of water occurs in a South-westerly direction, following the topography and generally flowing towards the river.

The volumetric-, Neutron probe- and Diviner datasets showed similar results to that of the CMD datasets, although the anomalies did not always seem to be in the exact same geographical location. The reason for this was the fact that the CMD datasets had a lot more data points, where measurements were taken. In general, the Western half of the field had a higher amount of SMC than the Eastern half. The first anomaly was visible (although very small when compared to the deeper CMD measurements) in all three the above-mentioned datasets. The accumulation of water on the surface in the centre of the pivot (discussed as the second anomaly) was seen in all three months discussed for all the datasets. This accumulation of water increased in magnitude and size with the increase of depth (up to the maximum depth discussed for these three datasets – which was up to 100 centimetres), for January, March and June. The third anomaly was also visible in all three months at all the depths discussed for the volumetric- Neutron probe- and Diviner data.

The first and third anomalies were both due to natural causes, the first anomaly being a result of the geology and the topography in this area, as well as the constrictive layer thought to be a palaeochannel. The third anomaly, on the other hand, was caused by a sudden increase of clay content in the soil. To mitigate the effects of over saturation for these two problematic areas, better care should be taken with the irrigation of the field. This could either be done manually, by adjusting the speed at which the pivot moves over these anomalies, or to manually decrease the amount of water given. Although these suggestions are plausible, it would not be a viable option. A better option would be to consider precision farming. To achieve this, either drip irrigation systems need to be installed, or a computer-guided system (that automatically adjusts the amount of water given at these specific anomalies) could be installed on the pivot. The second anomaly caused some concern, due to the loss of large amounts of water that was caused by a leakage below ground in the pipe leading to the centre of the pivot. This was of great concern, because as mentioned, South Africa is a water scarce country, and this unnecessary waste of water could possibly lead to environmental issues and affect the quality and quantity of crop production.

The third and final aim of this study was to determine which apparatuses would be the most cost- and time efficient method for both large scale and small scale use. By comparing and looking at the results discussed, experiences in the field (i.e. time and labour), the resolution of results, the data collection, -management and –processing, the CMD was considered as the overall best method, of those used in this study, for the geophysical investigation of indicating SMC (if the proper steps were taken to include possible environmental factors and variables). Therefore, the CMD would be the best choice of a long-term investment for industrial, consulting and large-scale commercial use of indicating SMC. The CMD is easy to setup, easy to use, does not require manual in-field calibration (if EC measurements will be used) and is very time- and labour efficient. The biggest disadvantage of the CMD is that the apparatus is expensive, and would therefore not be a viable choice for smaller scale SMC investigations. Another disadvantage is that the CMD gives measurements as electrical conductivity, therefore a calibration protocol would be necessary for volumetric measurements. Thus, with regards to farming, personal- and other smaller scale uses or investigations, the Diviner 2000 would be the most effective way of measuring SMC. The Diviner was not only the least expensive apparatus used in this study, but is also lightweight, easy to operate and calibrate, as well as being labour- and cost effective. Unlike the Neutron probe, the Diviner poses no risk to human health and does not require annual calibration. The complicated transfer and management of the data, which is stored on the control unit, is the biggest disadvantage of the Diviner 2000. However, if the Diviner is used for small scale SMC estimates (e.g. day to day irrigation schedules), the SF measurements could be used as a good indication of SMC increases or decreases of over time.

Apart from the set aims and objectives for this study, an observation was made after looking at the geology of the study area and comparing it to the SMC results. It was discovered that areas with higher SMC measurements were found mainly on the Pretoria Group, located to the Northwest of the pivot. Whereas the measurements taken on the Madzaringwe Formation (to the Southeast), generally had lower SMC's. This phenomenon was mainly attributed to the K of the different geologies. The basalts found to the Northwest (Pretoria Group) were considered to have a much smaller K than that of the sandstones, found to the Southeast (Madzaringwe Formation). This presumably leads to an accumulation of water on top of the basalts, although the exact depth of the accumulation is not certain. This phenomenon, together with the possibility of the palaeochannel, is most likely the cause of the large anomaly seen to the Northwest (discussed as the first anomaly).

With the increase of water scarcity, especially in South Africa, droughts are seen as being common and a recurring phenomenon. Such climatic events could greatly affect activities such as farming (e.g. crop production and livestock). The reason for this, is the influence that SMC

has on plant growth and the transport of nutrients in soil. Therefore, the proper management of SMC could lead to higher quality and quantity crop yields. SMC management does not only play an important role in farming, but could also be useful in smaller and larger scale industries (such as consulting or environmental rehabilitation). The use of geophysical methods to assess and monitor SMC, is becoming a more common and effective way of collecting soil moisture data. This study showed that the CMD would be the preferred method for investigations on a larger scale, and the Diviner for smaller scale investigations, with time-, labour- and cost efficiency in mind. This study looked at the statistical and visual comparisons of three different geophysical methods, and their results were used to identify three problematic areas on the study area. With the use of the different geophysical methods, the soil mapping and the available literature on the study area, the causes of the problematic areas were delineated and discussed. This study showed that the use of geophysical methods could be effectively used for SMC measuring, -monitoring and -management on both small- and large-scale investigations.

5.3 RECOMMENDATIONS FOR FURTHER RESEARCH

- Conduct the study on a smaller scale, where all instruments could be used on the same grid system. This could possibly increase the accuracy of the statistical comparison of the data, as it eliminates variable such as scale differences.
- A more scientific approach of determining the labour intensity and cost efficiency of each method used at different scales.
- Look at the possibility of precision farming and the implications therefore, by using the apparatuses and results found with this study.
- Look at the implications and influence that the palaeochannel has on the flow of water by modelling the underground water flow, as well as considering solutions to minimize the effect of the palaeochannel on the pivot.
- Using the CMD series of apparatuses to investigate the possibility of delineating soil formations and geological units.

CHAPTER 6: PROJECT MANAGEMENT

Project management is a pivotal part of any study, in any discipline, and is crucial to the success and quality of any research report or study. Therefore, the project management of this study is represented in Figure 27 as a Gantt chart (created in *Microsoft Power Point* with the *Office Timeline* add-on), where all the milestones, problems encountered and tasks were given.

All the outcomes, milestones and deadlines set were reached within the determined timeframe, as shown in Figure 27. The problems encountered were mainly during the first field visit, where half of the field caught on fire and the farmer had to plant crops on this half. This did not have a major effect on the project management of the study. The second main difficulty encountered was that the CMD apparatuses could not be used during the March data collection. This did not result in a change of planning or structure to the study, as the January and June data shows measurements taken in the wet- and dry season.

This shows that proper planning and time management is of critical importance, together with taking into account that difficulties might occur. It is crucial to set deadlines in the initial planning of the project, and it is even more crucial to meet the pre-determined deadlines. This is the key to delivering quality and trust worthy results, together with the completion of the project by the set due date.

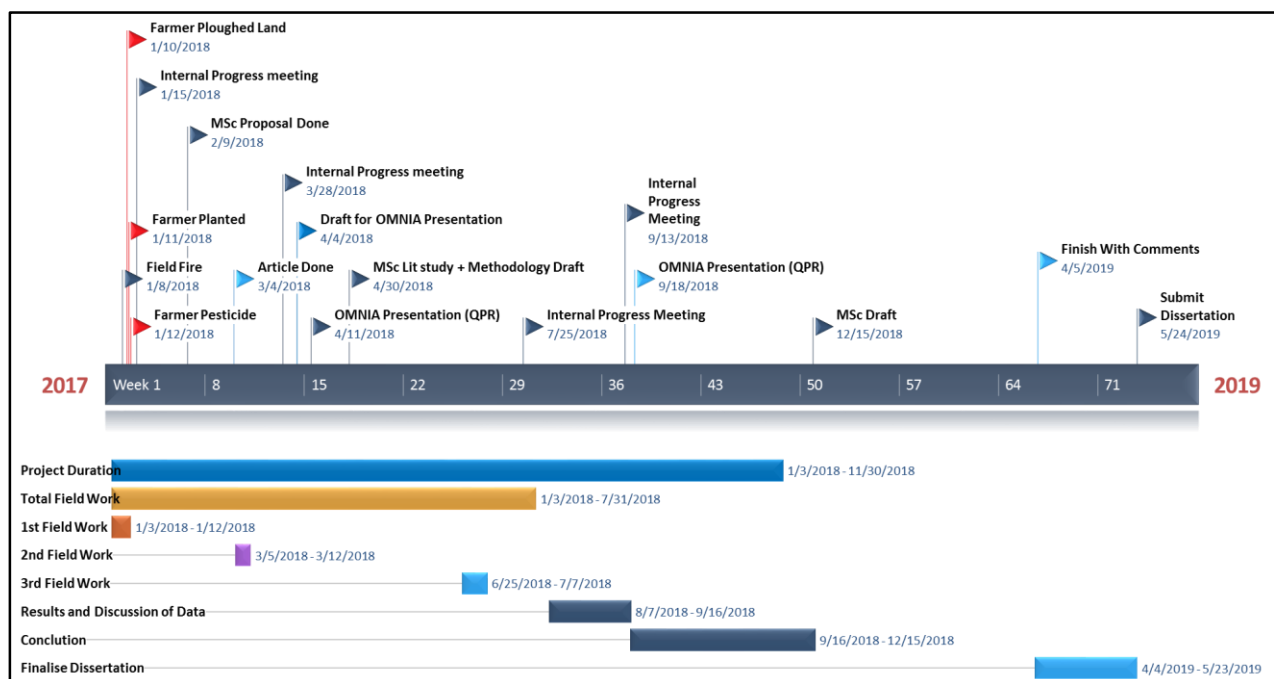


Figure 27: Gantt chart showing the project management of the study.

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CHAPTER 8: APENDICES

8.1 APPENDIX 1: DENSITY CALIBRATION AND RAW DATA

Table 20: The calibrated measurements taken with the Neutron probe and the calculated densities of the water, loose soil and compacted soil.

	Calibration measurements	Calculated densities
Water	1.55366667	0.997
Loose soil	1.708	1.19397114
Compacted soil	2.131	1.76478993

Table 21: Raw dry density measurements taken in the field with the Neutron probe at 32 seconds.

Neutron Probe Dry Density Counts									
profile	Clip numbers (20 cm intervals)								
	1	2	3	4	5	6	7	8	9
1.1	1.763333	1.751333	1.815	1.855	1.942				
2.2	1.828667	1.840333	1.888	1.855	1.788				
2.3	1.767333	1.741667	1.776	1.697	1.769	2.129	2.216	2.259	
2.4	1.847267	1.738667	1.777	1.914	1.894				
2.5	1.841333	1.743	1.783	1.829					
2.6	1.727667	1.718	1.754	1.826					
3.1	1.77	1.746333	1.837	1.899	1.915	1.866			
3.2	1.819167	1.662	1.723	1.822	1.823				
3.3	1.867667	1.831333	1.94	1.855	1.748				
3.4	1.913667	1.712333	1.734	1.777					
3.5	1.889	1.72	1.772	1.751					
3.6	1.924	1.746							
3.7	1.809	1.887333	1.866	2.032	2.147				
4.1	1.777333	1.696	1.747	1.698	1.654	1.737	1.762	1.912	
4.2	1.576667	1.704333	1.79	1.727	1.724	1.757	1.702	1.848	2.125
4.3	1.946667	1.683333	1.696	1.728	1.701	1.795	1.784		
4.4	1.707667	1.759667	1.877	1.901	2.02				
4.5	1.865	1.705	1.749	1.678	1.587	1.933	2.098		
4.6	1.836333	1.752333	1.787	1.885	1.925				
4.7	1.844667	1.78	1.898	2.034	2.002				
4.8	1.903667	1.695333	1.763						
4.9	1.924	1.788	1.63						
5.1	1.798667	1.719	1.752	1.794	1.819	1.797	1.802	2.025	1.982
5.2	1.745333	1.572667	1.673	1.807	1.727	1.783	1.792	1.822	1.907
5.3	1.768667	1.675667	1.67	1.673	1.614	1.67	1.702		
5.4	1.795667	1.828333	1.828	1.967	1.982				
5.5	1.858333	1.777333	1.826						

Neutron Probe Dry Density Counts (continued)									
profile	Clip numbers (20 cm intervals)								
	1	2	3	4	5	6	7	8	9
5.6	1.762	1.698	1.832	1.88					
5.7	1.753667	1.753667	1.853						
5.8	1.919	1.808	1.738						
5.9	1.874333	1.773	1.74						
6.1	1.869667	1.706	1.747	1.784	1.777	1.755	1.798	1.904	1.95
6.2	1.851667	1.701667	1.751	1.778	1.699	1.745	1.825	1.921	
6.3	1.643	1.620333	1.747	1.813	1.829	1.869	2.049		
6.4	1.821333	1.694667	1.755	1.913					
6.5	1.565333	1.739333	1.757	1.921	1.811	1.865			
6.6	1.729667	1.771667	1.702	1.915					
6.7	1.861333	1.856333	1.78	1.884					
6.8	1.767	1.734	1.894	1.83	1.938	2.011	2.115		
6.9	1.795333	1.783	1.828	1.799	1.773	1.907			
7.1	1.849333	1.700333	1.734	1.823	1.745	1.898	1.892	2.079	
7.2	1.743333	1.591667	1.636	1.807	1.96	1.949			
7.3	1.805	1.753667	1.753	1.874	1.891	2.089	2.078		
7.4	1.727333	1.702667	1.738	1.734	2.015	2.208			
7.5	1.748667	1.792667	1.874	1.956	2.099				
7.6	1.762667	1.711333	1.749	1.894	1.843				
7.7	1.740333	1.698667	1.737	1.781					
8.1	1.748667	1.671667	1.73	1.759	1.778	1.756	1.773	1.987	1.982
8.2	1.705	1.650667	1.658	1.608	1.605	1.66	1.775	1.633	1.679
8.3	1.630333	1.544333	1.748	1.769	1.794	1.857	1.977	1.911	
8.4	1.703333	1.616333	1.763	1.82	1.865	1.819	1.984	1.922	
8.5	1.766333	1.682	1.796	1.763	1.769				
8.6	1.770333	1.691333	1.708	1.885	2.082	2.265	2.164		
8.7	1.816667	1.731	1.698						
9.1	1.813333	1.653	1.719	1.712	1.711	1.732	1.684		
9.2	1.763667	1.616	1.541	1.845	1.95	2.016	2.115	2.039	
9.3	1.868667	1.718	1.7						
9.4	1.806667	1.69	1.716	1.795	1.827	1.888	1.919	1.964	1.918
9.5	1.822667	1.701333	1.711	1.774	1.83	1.971	1.933		

Table 22: Raw data for the calculated densities calculated, with the density calibration protocol.

Profile	Calculated Density (g/cm ³)								
	Clip numbers (20 cm intervals)								
	1	2	3	4	5	6	7	8	9
1.1	1.266169	1.250467	1.33419	1.387316	1.504267				
2.2	1.352296	1.367789	1.431451	1.387316	1.298559				
2.3	1.271411	1.237845	1.282782	1.179831	1.273596	1.76214	1.885136	1.946636	
2.4	1.377013	1.233933	1.284096	1.466418	1.439505				
2.5	1.369119	1.239585	1.291981	1.352738					
2.6	1.219608	1.207044	1.253953	1.348759					
3.1	1.274908	1.243936	1.363359	1.446223	1.467766	1.401997			
3.2	1.339705	1.134726	1.213539	1.343458	1.344783				
3.3	1.404224	1.355834	1.501556	1.387316	1.246112				
3.4	1.465968	1.19969	1.227852	1.284096					
3.5	1.432792	1.209641	1.277532	1.250032					
3.6	1.479912	1.243501							
3.7	1.326256	1.430556	1.401997	1.62727	1.78743				
4.1	1.284533	1.178538	1.244806	1.181125	1.12446	1.231761	1.264422	1.463722	
4.2	1.026057	1.189321	1.301192	1.21874	1.214839	1.257877	1.1863	1.37799	1.756531
4.3	1.510594	1.162182	1.178538	1.220041	1.185006	1.307779	1.293296		
4.4	1.19364	1.261367	1.416708	1.448913	1.610751				
4.5	1.400661	1.190185	1.247419	1.155307	1.039118	1.492079	1.718778		
4.6	1.362473	1.251774	1.297243	1.427427	1.481263				
4.7	1.373553	1.288037	1.444879	1.630027	1.586041				
4.8	1.4525	1.177676	1.265732						
4.9	1.479912	1.298559	1.093759						
5.1	1.312613	1.208342	1.251339	1.306461	1.339484	1.310415	1.317011	1.617629	1.558681
5.2	1.24263	1.021009	1.148869	1.323613	1.21874	1.291981	1.303826	1.343458	1.456987
5.3	1.273159	1.152302	1.145009	1.148869	1.073373	1.145009	1.1863		
5.4	1.308658	1.351853	1.351411	1.538228	1.558681				
5.5	1.391761	1.284533	1.348759						
5.6	1.264422	1.181125	1.356719	1.420726					
5.7	1.253518	1.253518	1.38465						
5.8	1.473162	1.324934	1.233064						
5.9	1.413139	1.278844	1.235672						
6.1	1.406897	1.19148	1.244806	1.293296	1.284096	1.255261	1.311734	1.452949	1.515117
6.2	1.382873	1.185869	1.250032	1.285409	1.182418	1.242195	1.347433	1.475861	
6.3	1.110371	1.081434	1.244806	1.331544	1.352738	1.406006	1.650734		
6.4	1.342574	1.176815	1.255261	1.46507					
6.5	1.011764	1.234802	1.257877	1.475861	1.328899	1.400661			
6.6	1.22221	1.277094	1.1863	1.467766					
6.7	1.395765	1.389094	1.288037	1.426086					
6.8	1.270974	1.227852	1.439505	1.354065	1.498847	1.598385	1.742527		
6.9	1.308218	1.291981	1.351411	1.313053	1.278844	1.456987			
7.1	1.379765	1.184143	1.227852	1.344783	1.242195	1.444879	1.436819	1.692321	
7.2	1.24002	1.045025	1.10142	1.323613	1.528703	1.51376			

Calculated Density (g/cm ³) (continued)									
Profile	Clip numbers (20 cm intervals)								
	1	2	3	4	5	6	7	8	9
7.3	1.320972	1.253518	1.252646	1.412693	1.435477	1.706234	1.690931		
7.4	1.219174	1.187163	1.233064	1.227852	1.603879	1.873746			
7.5	1.246983	1.304704	1.412693	1.523265	1.720173				
7.6	1.265296	1.198393	1.247419	1.439505	1.371335				
7.7	1.236106	1.181987	1.231761	1.289351					
8.1	1.246983	1.147153	1.222644	1.260495	1.285409	1.256569	1.278844	1.565511	1.558681
8.2	1.190185	1.120187	1.129591	1.065745	1.061934	1.132158	1.281469	1.097589	1.156596
8.3	1.094184	0.985364	1.246112	1.273596	1.306461	1.389983	1.551857	1.462374	
8.4	1.188026	1.076342	1.265732	1.340808	1.400661	1.339484	1.561412	1.477211	
8.5	1.2701	1.160463	1.309097	1.265732	1.273596				
8.6	1.275345	1.172508	1.194071	1.427427	1.696493	1.955255	1.81139		
8.7	1.336395	1.223945	1.181125						
9.1	1.331985	1.123178	1.208342	1.199257	1.19796	1.225247	1.163042		
9.2	1.266606	1.075917	0.981184	1.373996	1.515117	1.605252	1.742527	1.636923	
9.3	1.40556	1.207044	1.183712						
9.4	1.323173	1.170785	1.204447	1.307779	1.350085	1.431451	1.473162	1.534144	1.471813
9.5	1.344341	1.185437	1.19796	1.280156	1.354065	1.543677	1.492079		

8.2 APPENDIX 2: GRAVIMETRIC WATER CONTENT RAW DATA

Table 23: Wet mass (measured in grams) of samples taken in the field for the January gravimetric water content calculations.

January - Sample Wet Mass (g)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	348.12	357.59	358.96						
2.2	353.87	351.98	459.96	599.35					
2.3	356.35	357.16	356.84	356.29					
2.4	351.7	350.2	357.31						
2.5	352.63	353.9	354.96						
2.6	354.93	353.58	357.13	359.11					
3.1	348.43	350.69	364.09	343.24	350.33				
3.2	315.63	351.89	354.02	356.75	351.16	349.26			
3.3	340.93	349.07	352.98	350.57	328.19				
3.4	350.73	346.44	357.6	366.95	320.34				
3.5	349.72	351.19	349.38						
3.6		349.42	351.77						
3.7	351.22	349.93	424.4						
4.1	366.79	364.07	349.41	351.26	0	350.19	332.72	360.19	369.75
4.2	355.4	330.06	358.84	370.6	361.03	351.38	358.57		
4.3	354.67	362.36	389.91	365.18	339.84				
4.4	356.02	365.19	360.18	348.51					
4.5	346.3463	346.3263	346.3863	348.0863	348.1863	346.1063	346.7263	347.0363	570.2663
4.6	349.0463	351.5363	347.9563	346.2163	346.8763	353.3263	346.1063	362.0463	
4.7	300.4063	350.2563	346.9963	353.9263	345.7863	354.3263	346.6363	346.8663	347.7863
4.8	345.8063	347.9763	312.0563	346.3463	346.4163	348.0963	348.2863	346.0263	353.8263
4.9	345.5663	0	347.9663	347.9463	346.3663	347.5163	345.9463	346.3063	346.0163
5.1	356.62	347.06	363.3	354.42	352.16				
5.2	352.92	351.66	350.5	363.34	355.86	355.16	365.34		
5.3	351.43	345.03	353.52	354.03	355.07	357.52	355.2	360.32	
5.4	343.29	364.22	364.32	351.6	385.05				
5.5	352.98	355.16	387.55	373.84					
5.6	348.98	351.71	356.85	379.16					
5.7	350.8	350.21	522.81						
5.8	349.81	0	349.67	351.06					
5.9	351.6	350.85	349.57						
6.1	347.96	356.15	355.86	356.98	355.96	353.47			
6.2	352.14	357.37	352.72	355.99	351.57	357.78			
6.3	356.36	354.1	355.93	352.52	356.82	353.1	593.06	552.6	
6.4	354.82	353.24	532.35	352.62					
6.5	353.68	352.23	3356.88	356.78	593.79				
6.6	354.5	351.82	358.86	358.88					
6.7	354.24	356.52	355.26	350.13					
6.8	352.58	352.64	355.25	354.12	356.6	547.29			

January - Sample Wet Mass (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
6.9	356.43	351.08	358.06	357.23	354.84				
7.1	379.93	346.7163	363.06	351.55	346.9363	346.72	346.8263		
7.2	345.7	339.18	347.1763	346.3063	359.69	347.2163	346.6463		
7.3	345.01	249.81	346.1963	347.3163	365.58	347.4263	583.92		
7.4	353.59	357.09		350.62	353.37	590.04			
7.5	357.92	354.46	593.02	597.77					
7.6	357.43	358.04	359.52	359.71	304.81				
7.7	352.2	354.4	356.55	350.31	352.31	357.86			
8.1	346.0363	346.0763	346.9063	337.49	346.7963	352.34	351.31	347.0163	347.2663
8.2	346.7663	346.2163	347.7663	355.33	350.02	357.73	352.69	393.7	
8.3	358.93	349.52	349.74	347.01	351.81	358.72			
8.4	340.17	350.93	354.18	354.29	363.02	598.52	0	589.36	
8.5	350.13	351.5	350.95	499.72	355.61	383.4	361.25		
8.6	371.01	349.37	363.5	351.59	351.29	351.21	352	350.25	429.99
8.7	338.05	380.42	575.58	349.75					
9.1	358.45	350.92	354.16	353.9	354.28	354.23	352.69	351.58	
9.2	352.56	351.31	356.78	381.21	0	378.87	359.27	353.2	352.58
9.3	350.95	357.32	351.1	354.39	350.74	350.88			
9.4	350.2	379.82	395.79	407.36	379.72	370.19	352.91	591.51	
9.5	369.03	355.41	374.14	362.66	353.32	362.4	384.71	398.75	354.52

Table 24: Dry mass (measured in grams) of samples taken in the field for the January gravimetric water content calculations.

January - Sample Dry Mass (g)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	334.49	341.08	342.56						
2.2	329.2	311.56	398.29	510.7					
2.3	334.07	331.27	322.77	323.12					
2.4	333.22	331.61	335.28						
2.5	338.66	338.27	337.04						
2.6	343.91	344.71	339.42	342.82					
3.1	330.96	327.26	327.61	312.25	315.28				
3.2	295.15	330.17	326.41	324.52	317.92	317.12			
3.3	319.53	323.1	318.41	320.76	300.84				
3.4	334.23	330.05	339.31	345.25	303.41				
3.5	333.5	330.08	329.41						
3.6	269.22	327.97	330.01						
3.7	325.9	320.97	383.5						
4.1	363.89	359.2	343.23	324.88	0	331.04	307.93	331.87	341.26
4.2	343.25	312.45	326.79	336.09	328.98	320.15	323.3		
4.3	334.15	341.44	365.02	339.22	313.69				
4.4	333.69	343.44	333.23	322.37					
4.5	330.55	319.37	332.17	328.78	324.92	323.28	317.07	315.92	506.65
4.6	337.43	345.91	330.65	328.35	323.93	323.45	315.86	334.77	
4.7	298.56	342.93	331.21	330.08	317.52	321.88	326.46	316.59	318.54
4.8	327.95	341.44	330.98	330.22	326.82	334.34	323.07	326.18	330.23
4.9	331.24	340.36	335.12	329.73	336.14	331.72	325.89	327.06	324.62
5.1	0	326.03	332.6	320.39	316.89				
5.2	339.34	335.04	330.54	338.05	326.43	322.96	330.71		
5.3	335.84	331.53	336	332.89	332.38	333.8	333.26	340.43	
5.4	313.46	331.63	329.92	320.8	348.4				
5.5	333.56	323.59	352.78	342.92					
5.6	323.48	320.37	325.28	344.46					
5.7	319.74	321.89	473.96						
5.8	325.34	329.06	324.58	325.76					
5.9	337.46	334.86	334.96						
6.1	329.48	336.96	327.99	328.13	325.54	319.92			
6.2	341.32	342.3	333.08	334.2	325.64	326.32			
6.3	340.61	336.8	326.95	324.93	325.71	322.74	530.72	488.84	
6.4	328.68	322.73	479.38	321.21					
6.5	327.91	320.99	322.89	322.34	525.89				
6.6	325.44	323.72	327.75	328.12					
6.7	326.36	326.07	0	320.76					
6.8	328.92	324.72	320.67	322.58	322.2	480.44			
6.9	348.2	335.25	334.69	325.87	324.95				
7.1	360.55	336.75	342.44	328.63	320.73	314.38	306.41		

January - Sample Dry Mass (g) (continued)									
Profile	Depth (20 cm)								
	20	40	60	80	100	120	140	160	180
7.2	336.78	315.88	318.45	320.98	331.62	328.14	313.81		
7.3	324.94	0	318.26	311.23	331.45	335.64	422.44		
7.4	0	326	0	322.8	326.31	537.89			
7.5	321.53	323.98	529	538.64					
7.6	335.42	327.04	329.62	324.56	275.99				
7.7	345.57	337.18	0	331.27	335.09	335.91			
8.1	341.39	334.87	337.68	323.5	327	333.23	329.95	321.88	322
8.2	335.67	328.18	326.4	328.71	318.43	324.09	318.98	345.87	
8.3	349.62	335.8	323.29	314.93	319.6	324.9			
8.4	326.34	330.35	329.45	328.06	326.72	535.68	0	524.4	
8.5	331.6	324.15	322.59	451.86	324.43	352.71	331.92		
8.6	366.22	340.92	346.75	333.2	331.41	329.99	329.43	326.79	397.27
8.7	334.95	373.43	361.93	337.8					
9.1	349.81	342.52	345.95	333.77	338.78	335.93	324.35	0	
9.2	347.58	346.81	341.29	336.37	0	364.65	344.21	339.47	340.81
9.3	348.52	354.78	346.75	347.59	341.59	338.65			
9.4	344.42	364.98	368.17	381.56	344.14	333.78	313.81	537.23	
9.5	366.29	344.06	356	338.18	320.06	331.19	354.81	372.68	332.11

Table 25: Gravimetric water content calculated for January, by subtracting the wet mass (g) from the dry mass (g) of each sample.

January - Gravimetric Water Content (g)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	0.040749	0.048405	0.047875						
2.2	0.074939	0.129734	0.154837	0.173585					
2.3	0.066693	0.078154	0.105555	0.102655					
2.4	0.055459	0.05606	0.065706						
2.5	0.041251	0.046206	0.053169						
2.6	0.032043	0.025732	0.052177	0.047518					
3.1	0.052786	0.071594	0.111352	0.099247	0.111171				
3.2	0.069388	0.065784	0.084587	0.099316	0.104555	0.10135			
3.3	0.066973	0.080378	0.108571	0.092936	0.090912				
3.4	0.049367	0.049659	0.053904	0.062853	0.055799				
3.5	0.048636	0.063954	0.060624						
3.6	0	0.065402	0.065937						
3.7	0.077693	0.090227	0.106649						
4.1	0.007969	0.013558	0.018005	0.081199	0	0.057848	0.080505	0.085335	0.083485
4.2	0.035397	0.056361	0.098075	0.102681	0.097422	0.097548	0.109094		
4.3	0.06141	0.06127	0.068188	0.076529	0.083363				
4.4	0.066918	0.06333	0.080875	0.081087					
4.5	0.047788	0.084404	0.042798	0.058721	0.071606	0.070608	0.093532	0.098494	0.125563
4.6	0.034426	0.016265	0.05234	0.054412	0.070837	0.092367	0.095758	0.081478	
4.7	0.006184	0.021364	0.047662	0.072244	0.089022	0.100802	0.061803	0.095632	0.091813
4.8	0.054448	0.019143	-0.05717	0.048835	0.05996	0.041144	0.078052	0.060844	0.071454
4.9	0.04325	0	0.038333	0.055246	0.030423	0.047619	0.061543	0.058846	0.065912
5.1	0	0.064503	0.092303	0.106214	0.1113				
5.2	0.040019	0.049606	0.060386	0.074811	0.090157	0.099703	0.104714		
5.3	0.046421	0.04072	0.052143	0.063504	0.068265	0.071061	0.065834	0.058426	
5.4	0.095164	0.098272	0.104268	0.09601	0.105195				
5.5	0.05822	0.097562	0.09856	0.090167					
5.6	0.07883	0.097824	0.097055	0.100737					
5.7	0.097141	0.08798	0.103068						
5.8	0.075214	0	0.0773	0.077665					
5.9	0.041901	0.047751	0.043617						
6.1	0.056088	0.05695	0.084972	0.087922	0.093445	0.10487			
6.2	0.0317	0.044026	0.058965	0.0652	0.079628	0.096408			
6.3	0.046241	0.051366	0.088637	0.084911	0.095514	0.09407	0.117463	0.130431	
6.4	0.07953	0.094537	0.110497	0.097786					
6.5	0.078589	0.097324	9.396358	0.106844	0.129114				
6.6	0.089294	0.086803	0.09492	0.093746					
6.7	0.085427	0.093385	0	0.091564					
6.8	0.071932	0.085982	0.107837	0.097774	0.106766	0.139143			
6.9	0.023636	0.047218	0.069826	0.096235	0.091983				
7.1	0.053751	0.029595	0.060215	0.069744	0.081708	0.102869	0.131903		
7.2	0.026486	0.073762	0.090206	0.078903	0.084645	0.058134	0.104637		

January - Gravimetric Water Content (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	0.061765	0	0.087778	0.115947	0.102972	0.035116	0.382255		
7.4	0	0.095368	0	0.086183	0.082927	0.096953			
7.5	0.113178	0.09408	0.121021	0.109776					
7.6	0.065619	0.09479	0.090711	0.1083	0.104424				
7.7	0.019186	0.051071	0	0.057476	0.051389	0.065345			
8.1	0.01361	0.033464	0.027322	0.043246	0.060539	0.057348	0.064737	0.078092	0.078467
8.2	0.033057	0.054958	0.06546	0.080983	0.099205	0.103798	0.105681	0.138289	
8.3	0.026629	0.040858	0.081815	0.101864	0.100782	0.104094			
8.4	0.042379	0.062298	0.075065	0.079955	0.111104	0.117309	0	0.123875	
8.5	0.055881	0.084375	0.087913	0.105918	0.096107	0.087012	0.088365		
8.6	0.01308	0.024786	0.048306	0.055192	0.059986	0.064305	0.068512	0.071789	0.082362
8.7	0.009255	0.018718	0.590308	0.035376					
9.1	0.024699	0.024524	0.023732	0.060311	0.045752	0.054476	0.087375		
9.2	0.014328	0.012975	0.045387	0.133306	0	0.038996	0.043752	0.040445	0.034535
9.3	0.006972	0.007159	0.012545	0.019563	0.026786	0.036114			
9.4	0.016782	0.04066	0.07502	0.067617	0.103388	0.109084	0.124598	0.101037	
9.5	0.00748	0.032988	0.050955	0.072387	0.103918	0.094236	0.08427	0.069953	0.067478

Table 26: Wet mass (measured in grams) of samples taken in the field for the March gravimetric water content calculations.

March - Sample Wet Mass (g)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	356.64	361.87	357	364.79	354.26	353.94	346.86	360.33	355.04
2.2	361.31	358.68	365.68	354.9	380.1	350.97			
2.3	356.55	352.82	353.84	359.74	353.75	355.22	352.82	360.01	369.08
2.4	359.36	355.77	350.47	358.17	351.69	355.71	366.59	367.59	
2.5	350.87	364.5	365.79	350.78	374.39	362.2	371.94		
2.6	363.46	353.52	358.93	358.13	368.05				
3.1	357.07	350.13	356.98	357.31	433.67	395.04	382.72		
3.2	410.91	457.36	427.98	412.75	355.61	454.21	422.79	350.99	
3.3	413.67	352.32	430.75	416.83	410.33	414.45	444.08		
3.4	405.71	403.63	356.6	423.82	356.01	405.52	389.23		
3.5	437.66	410.24	375.68	427.56					
3.6	335.65	315.68	385.65						
3.7	363.25	376.95	494.9	350.9	384.17	360.18			
4.1	403.12	365.86	393.29	372.86	357.36	358.05	369.26	369.49	351.75
4.2	359.07	372.83	376.78	359.78	366.94	352.64	355.5	347.96	349.96
4.3	358.28	395.97	430.39	342.82	357.15	300.36	325.68	354.27	
4.4	362.45	355.07	366.74	449.85	416.54	341.77	359.19	391.51	392.16
4.5	427.57	370.68	371.79	395.02	366.1	394.8	459.58	416.56	407.88
4.6	380.43	438.04	452.47	352.7	353.73	356.42	362.74	391.8	
4.7	461.23	363.39	358.62	439.53	358.28	372.74	312.94	355.31	350.11
4.8	353.04	357.94	350.7	362.88	359.99				
4.9	0	358.64	367.83	388.04	385.48	353.77	346.31	390.73	361.99
5.1	311.68	270.59	345.03	341.38	283.83	346.89	266.26	352.22	345.55
5.2	320.83	365.37	313.51	351.32	378.49	357.69	400.17	354.83	354.8
5.3	353.83	356.05	317.19	324.88	351.2	391.38	357.28	369.23	374.69
5.4	373.86	407.26	462.26	419.29	455.57	444.43	428.73	389.78	494.09
5.5	357.81	434.02	441.29	433.54	450.7	445.76	360.98	357.5	350.81
5.6	476.21	359.37	428.48	352.26	467.96	350.16	438.1		
5.7	360.91	357.58	363.79	354.15	440.34	363.93	446.15		
5.8	404.08	359.87	508.26	439.77	457.52	353.2	483.32	429.08	422.25
5.9	355.25	363.06	355.13	356.27	356.01	374.91	508.28	360.91	454.97
6.1	352.89	359.36	371.02	391.7	354.66	358.76	352.52	387.82	350.17
6.2	355.07	360.52	350.92	451.81	350.88	352.17	360.42	358.45	
6.3	359.64	357.59	465.34	418.26	454.41	536.4			
6.4	359.17	353.6	355.95	358.13					
6.5	354.59	358.93	432.88	352.46	497.76	541.72	351.66		
6.6	458.75	414	414.04	410.68	350.5	473.66			
6.7	350.97	351.39	373.21	363.2	352.78	365.02			
6.8	572.93	380.86	439.22	352.7	455.42	395.57	384.65	520.67	457.69
6.9	351.23	420.78	353.43	355.36	475.29	355.92	382.6	356.2	351.24
7.1	451.08	410.15	467.53	591.11	559.81	513.44	473.41	359.73	
7.2	492.15	519.01	437.01	578.19	535.27	557.43	375.44	421.17	485.62

March - Sample Wet Mass (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	459.19	350.61	367.25	507.76	469.79	533.75			
7.4	543.83	552.82	558.57						
7.5	528.23	357.66	510.93	407.89	562.57	540.83			
7.6	500.85	472.5	549.94	502.69	482.57				
7.7	375.87	356.67	398.11						
8.1	358.86	414.34	360.17	353.13	357.48	352.46	368.92	361.1	354.88
8.2	355.37	376.84	350.56	418.5	366.87	360.25	365.38	354.31	407.51
8.3	367.37	356.5	351.09	579.19	490.29	365.45	511.2	458.2	
8.4	517.28	371.26	364.93	393.47	577.4	430.6	506.69	368.24	
8.5	369.12	441.84	352.58	465.28	400.9	529.37			
8.6	351.3	355.41	567.12	406.89	599.82	480.42	491.8	539.84	507.3
8.7	362.95	466.44	372.33	514.82					
9.1	392.82	390.06	414.52	436.56	410.46	387.52	379.5		
9.2	348.57	447.81	396.76	409.21	374.07	415.38	402.03	426.79	400.09
9.3	438.87	394.17	501.78						
9.4	509.74	498.95	380.85	421.34	419.28	386.48	376.82	423.61	466.32
9.5	395.43	501.46	451.74	480.86	363.18	397.86			

Table 27: Dry mass (measured in grams) of samples taken in the field for the March gravimetric water content calculations.

March - Sample Dry Mass (g)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	339.84	343.91	337.92	344.58	335.14	335.19	328.7	340.02	336.51
2.2	352.94	348.26	350.09	330.99	328.58	309.4			
2.3	336.95	331.17	330.51	330.46	325.93	328.08	323.85	330.62	339.44
2.4	341.55	337.11	331.73	338.83	332.8	335.98	344.95	344.3	
2.5	336.82	350.87	351.82	337.06	358.66	345.62	350.36		
2.6	344.79	336.86	338.61	333.03	343.98				
3.1	339.77	329.89	333.87	330.45	393.29	354.32	364.87		
3.2	383.84	425.63	397.61	381.6	329.72	412.66	378.36	318.54	
3.3	390.41	330.19	404.09	386.29	375.44	374.59	396.89		
3.4	383.4	382.2	339.59	400.56	337.61	382.32	364.85		
3.5	421.15	395.19	379.36	404.97					
3.6	318.05	298.75	362.68						
3.7	342.23	352.04	360.77	322.11	355.13	332.74			
4.1	388.01	356.98	375.8	355.43	340.22	338.29	345.79	339.51	331.85
4.2	342.14	354.25	359.92	329.48	335.07	0	323.5	314.96	318.18
4.3	344.1	376.57	405.73	322.94	332.19	283.78	306.18	328.78	
4.4	352.04	345.95	354.39	433.14	398.69	326.58	342.1	370.15	366.26
4.5	403.39	347.37	346.99	351.5	338.89	363.11	417.88	379.4	369.71
4.6	358.31	407.73	417.39	323.82	324.26	326.47	332.7	360.21	
4.7	435.4	344.83	338.95	413.71	331.88	348.48	295.71	335.31	332.34
4.8	333.99	338.97	333.85	345.15	343.7				
4.9	0	349.64	356.25	373.17	371.08	346.32	332.26	361.99	344.16
5.1	301.07	260.87	322.97	315.41	261.81	319.67	247.08	323.48	317.7
5.2	309.48	353.58	297.73	330.6	347.52	326.65	364.98	324.33	322.36
5.3	338.24	344.75	301.83	312.66	328.79	362.99	333.11	340.95	344.31
5.4	343.86	373.43	423.28	384.39	416.31	403.86	389.27	352.62	440.57
5.5	341.1	412.22	416.71	406.19	418.26	408.64	330.77	327.63	324.4
5.6	437.75	331.29	401.94	324.37	421.96	316.33	397.88		
5.7	351.17	347.61	347.14	333.6	414.84	336.05	416.11		
5.8	377.77	338.86	477.43	412.81	429.92	332.71	451.32	399.61	396.92
5.9	337.11	346.91	338.49	335.78	332.51	346.56	469.98	334.53	419.59
6.1	335.14	337.59	346.78	362.98	328.46	328.67	324.12	354.95	321.68
6.2	348.25	344.11	333.72	422.52	326.46	326.15	333.47	333.31	
6.3	344.04	335.14	435.91	389.85	420.82	497.19			
6.4	331.44	324.17	326.85	334.88					
6.5	338.14	335.97	389.68	319.55	453.18	492.01	321.43		
6.6	422.95	385.8	383.14	377.34	322.29	442.7			
6.7	333.2	332.17	351.98	337.81	332.93	331.1			
6.8	525.2	355.64	406.01	326.46	417.11	360.07	353.07	468.75	409.54
6.9	337.22	401.92	337.87	335.23	442.47	329.31	347.51	323.86	318.88
7.1	442.77	395.43	440.04	546.72	509.36	472.92	434.1	329.53	
7.2	483.79	508.35	414.29	533.42	493.43	510.83	345.47	390.58	450.4

March - Sample Dry Mass (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	450.16	336.39	334.41	450.65	421.89	475.52			
7.4	530.64	510.67	513.11						
7.5	487.31	327.48	461.03	368.65	510.53	490.14			
7.6	480.75	437.24	495.34	436.18	453.96				
7.7	368.53	346.34	380.54						
8.1	355.61	410.53	351.94	342.93	342.33	338.7	347.49	342.66	335.3
8.2	351.59	369.68	340.48	395.06	342	342.62	345.28	342.36	370.4
8.3	361.34	343.72	331.04	530.49	434.53	331.1	460.13	405.01	
8.4	502.37	355.73	344	359.36	507.79	386.74	453.31	339.45	
8.5	359.19	417.58	330.2	425.38	374.4	490.13			
8.6	346.4	346.39	545.89	393.4	576.48	460.1	469.88	515.45	483.43
8.7	357.94	459.43	359.21	482.81					
9.1	387.06	384.25	407.7	427.5	401.12	378.86	373.03		
9.2	344.88	443.22	394.89	404.79	371.51	409.94	396.47	420.97	391.48
9.3	433.03	384.32	484.35						
9.4	503.26	492.64	369.8	400.93	399.44	369.64	358.91	399.21	434.67
9.5	392.85	495.1	428.99	451.66	343.98	381.13			

Table 28: Gravimetric water content calculated for March, by subtracting the wet mass (g) from the dry mass (g) of each sample.

March - Gravimetric Water Content m(g)									
Profile	Depth (20 cm)								
	20	40	60	80	100	120	140	160	180
1.1	0.049435	0.052223	0.056463	0.058651	0.057051	0.055938	0.055248	0.059732	0.055065
2.2	0.023715	0.02992	0.044531	0.072238	0.156796	0.134357			
2.3	0.058169	0.065374	0.070588	0.088604	0.085356	0.082724	0.089455	0.088894	0.08732
2.4	0.052145	0.055353	0.056492	0.057079	0.056761	0.058724	0.062734	0.067644	
2.5	0.041714	0.038846	0.039708	0.040705	0.043858	0.047972	0.061594		
2.6	0.054149	0.049457	0.06001	0.075369	0.069975				
3.1	0.050917	0.061354	0.069219	0.081283	0.102672	0.114924	0.048922		
3.2	0.070524	0.074548	0.076381	0.08163	0.078521	0.100688	0.117428	0.101871	
3.3	0.059578	0.067022	0.065975	0.07906	0.092931	0.10641	0.118899		
3.4	0.05819	0.05607	0.05009	0.058069	0.054501	0.060682	0.066822		
3.5	0.039202	0.038083	-0.0097	0.055782					
3.6	0.055337	0.056669	0.063334						
3.7	0.061421	0.070759	0.371788	0.089379	0.081773	0.082467			
4.1	0.038942	0.024875	0.046541	0.049039	0.050379	0.058411	0.067874	0.088304	0.059967
4.2	0.049483	0.052449	0.046844	0.091963	0.095114		0.098918	0.104775	0.099881
4.3	0.041209	0.051518	0.060779	0.061559	0.075138	0.058426	0.063688	0.077529	
4.4	0.029571	0.026362	0.034849	0.038579	0.044772	0.046512	0.049956	0.057706	0.070715
4.5	0.059942	0.067104	0.071472	0.123812	0.080292	0.087274	0.099789	0.097944	0.103243
4.6	0.061734	0.074338	0.084046	0.089185	0.090884	0.091739	0.090292	0.087699	
4.7	0.059325	0.053824	0.058032	0.062411	0.079547	0.069617	0.058267	0.059646	0.053469
4.8	0.057038	0.055964	0.050472	0.051369	0.047396				
4.9		0.025741	0.032505	0.039848	0.038806	0.021512	0.042286	0.079394	0.051807
5.1	0.035241	0.03726	0.068304	0.082337	0.084107	0.08515	0.077627	0.088846	0.087661
5.2	0.036674	0.033345	0.053001	0.062674	0.089117	0.095025	0.096416	0.09404	0.100633
5.3	0.046092	0.032777	0.05089	0.039084	0.068159	0.078212	0.072559	0.082945	0.088234
5.4	0.087245	0.090593	0.09209	0.090793	0.094305	0.100456	0.101369	0.105383	0.121479
5.5	0.048989	0.052884	0.058986	0.067333	0.077559	0.090838	0.091332	0.09117	0.081412
5.6	0.087858	0.08476	0.06603	0.085982	0.109015	0.106945	0.101086		
5.7	0.027736	0.028682	0.047963	0.061601	0.061469	0.082964	0.072192		
5.8	0.069646	0.062002	0.064575	0.065308	0.064198	0.061585	0.070903	0.073747	0.063816
5.9	0.05381	0.046554	0.04916	0.061022	0.070675	0.081804	0.081493	0.078857	0.08432
6.1	0.052963	0.064487	0.0699	0.079123	0.079766	0.091551	0.087622	0.092605	0.088566
6.2	0.019584	0.047688	0.05154	0.069322	0.074802	0.079779	0.080817	0.075425	
6.3	0.045344	0.066987	0.067514	0.072874	0.07982	0.078863			
6.4	0.083665	0.090786	0.089032	0.069428					
6.5	0.048648	0.068339	0.11086	0.102989	0.098372	0.101035	0.094048		
6.6	0.084644	0.073095	0.080649	0.088355	0.08753	0.069934			
6.7	0.053331	0.057862	0.060316	0.075161	0.059622	0.102446			
6.8	0.09088	0.070914	0.081796	0.080377	0.091846	0.098592	0.089444	0.110763	0.117571
6.9	0.041546	0.046925	0.046053	0.060048	0.074175	0.080805	0.100976	0.099858	0.10148
7.1	0.018768	0.037225	0.062472	0.081193	0.099046	0.08568	0.090555	0.091646	
7.2	0.01728	0.02097	0.054841	0.08393	0.084794	0.091224	0.086751	0.078319	0.078197

March - Gravimetric Water Content (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	0.02006	0.042272	0.098203	0.126728	0.113537	0.122455			
7.4	0.024857	0.082539	0.088597						
7.5	0.083971	0.092158	0.108236	0.106442	0.101933	0.103419			
7.6	0.04181	0.080642	0.110227	0.152483	0.063023				
7.7	0.019917	0.029826	0.046171						
8.1	0.009139	0.009281	0.023385	0.029744	0.044256	0.040626	0.061671	0.053814	0.058395
8.2	0.010751	0.019368	0.029605	0.059333	0.072719	0.051456	0.058214	0.034905	0.100189
8.3	0.016688	0.037181	0.060567	0.091802	0.128323	0.103745	0.11099	0.13133	
8.4	0.029679	0.043657	0.060843	0.094919	0.137084	0.11341	0.117756	0.084814	
8.5	0.027646	0.058097	0.067777	0.093798	0.07078	0.08006			
8.6	0.014145	0.02604	0.038891	0.034291	0.040487	0.044164	0.04665	0.047318	0.049376
8.7	0.013997	0.015258	0.036525	0.066299					
9.1	0.014881	0.01512	0.016728	0.021193	0.023285	0.022858	0.017344		
9.2	0.010699	0.010356	0.004735	0.010919	0.006891	0.01327	0.014024	0.013825	0.021993
9.3	0.013486	0.02563	0.035986						
9.4	0.012876	0.012809	0.029881	0.050907	0.04967	0.045558	0.049901	0.061121	0.072814
9.5	0.006567	0.012846	0.053032	0.06465	0.055817	0.043896			

Table 29: Wet mass (measured in grams) of samples taken in the field for the June gravimetric water content calculations.

June - Sample Wet Mass (g)									
Profile	Depth (20 cm)								
	20	40	60	80	100	120	140	160	180
1.1	440.53	353.32	359.01	352.88	355.22				
2.2	357.17	355.06	374.57	360.45	356.94	360.28	546.38		
2.3	319.83	373.41	361.39	354.76	367.79	350.76	372.14	389.86	574.36
2.4	354.74	358.05	356.45	368.97	354.86	355.96			
2.5	358.02	359.81	353.36	353.21	351.82	353.37			
2.6	351.79	359.78	359.61						
3.1	358.68	372.18	354.21	408.81	355.35	360.54	354.07	355.46	
3.2	373.92	393.42	359.26	363.33					
3.3	366.6	360.66	355.96	263.16					
3.4	353.72	279.54	358.89						
3.5	353.79	367.62	352.55	365.71					
3.6	368.33	359.58							
3.7	432.07	360.1	357.98	360.09					
4.1	354.58	331.33	312.47	340.56	357.85	361.13			
4.2	358.64	357.74	377.21	353.36	361.2	350.8	359.56	354.02	356.45
4.3	353.57	355.52	350.98	359.37	359.09				
4.4	357.76	359.31	357.75	358.18	359.92	357.9	363.76	351.69	
4.5	361.56	263.88	352.55	365.77	271.79	351.01	350.51	368.59	
4.6	350.58	351.73	380.84	295.87					
4.7	352.18	350.17	353.82	353.37	353.9	354.99	355.73	359.33	365.91
4.8	353.45	351.74	358.9	353.86	352.07	352.73	356.58	350.95	357.78
4.9	351.04	353.09	353.57	354.57					
5.1	360.33	357.26	355.1	349.08	357.71	359.68	351.92	352.49	359.97
5.2	352.21	356.1	352.58	358.15	347.34	359.13	358.65	356.73	
5.3	357.59	353.69	353.9	351.13	350.27	358.28			
5.4	354.5	358.66	354.66	351.45	351.09	352.09	356.55	350.48	
5.5	353.45	351.49	354.36	354.41					
5.6	369.41	360.02	356.88	354.57					
5.7	360.32	363.59	355.6	356.46	358.59	376.04	387.83	367.96	354.27
5.8	352.46	354.15	350.72	545.85	356.31	527.38			
5.9	359.9	351.16	352.49						
6.1	353.56	344.08	352.61	356.61	350.87	354.61	349.65	359.13	357.12
6.2	350.66	355.64	332	353	347.81	357.7	354.71	358.88	329.15
6.3	335.47	352.8	351.69	355.86	351.7	354.01	358.59		
6.4	352.8	351.13	350.25	353.7	356.33				
6.5	354.72	356.65	358.09	353.85	365.2	358			
6.6	351.09	352.56	360.16						
6.7	355.61	358.78	359.65	353.2					
6.8	356.2	351.36	361.72	363.24	358.23	354.26			
6.9	365.34	363.85	372.43	358.16	351.28	353.11	365.27	354.13	
7.1	365.2	352.58	353.64	354.2	350.49	350.29	351.67	352.11	
7.2	317.13	354.68	355.32	354.61	353.01	372.24			

June - Sample Wet Mass (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	350.89	356.66	357.24	355.03	354.46	357.24	356.41	359.07	359.12
7.4	355.94	359.25	364.02	359.75	353.35	356.56			
7.5	353.92	355.81	350.46	468.22	541				
7.6	353.97	354.98	353.68	352.93	357.86	355.05	431.96		
7.7	345.15	352.12	354.53	351.04					
8.1	356.61	358.27	355.26	354.64	350.38	354.17	351.61	358.57	354.38
8.2	360.25	351.97	352.57	354.71	354.34	352.24	353.48		
8.3	363.27	357.96	357.5	354.98	353.89	361.31	352.66	358.81	351.12
8.4	359.98	351.8	357.48	357.8	354.15	350.74	358.01	364.51	
8.5	352.32	349.31	348.9	351	351.12	354.96	355.62	354.09	
8.6	354.93	352.87	354.76	350.76	350.16	355.76	352.53		
8.7	352.92	357.34	352.72						
9.1	349.88	353.25	352.76	352.04	358.02	352.23			
9.2	355.49	356.92	355.34	350.01	354.05	351.12	350.47	357.74	347.52
9.3	351.17	358.68	356.56	351.4					
9.4	338.49	374.85	352.7	356.86	359.27	350.8	358.52	352.45	431.76
9.5	319.83	351.37	353.91	352.5	356.77	351.18	358.75	355.19	351.17

Table 30: Dry mass (measured in grams) of samples taken in the field for the June gravimetric water content calculations.

June - Sample Dry Mass (g)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	421.27	337.33	343.03	334.42	336.51				
2.2	346.7	338.31	343.95	321.71	320.51	323.55	485.57		
2.3	310.01	355.58	340.6	327.76	335.9	321.97	339.67	357.16	510.35
2.4	342.89	343.17	340.27	350.24	336.11	336.57			
2.5	349.56	348.52	340.13	339.42	337.45	338.57			
2.6	339.3	340.5	337.43						
3.1	353.27	336.32	349.13	396.07	341.11	334.69	322.29	319.35	
3.2	347.5	373.04	339.61	340.37					
3.3	338.74	335.39	330.64	246.3					
3.4	330.1	270.07	344.29						
3.5	334.37	352.66	337.29	350.25					
3.6	343.74	338.59							
3.7	417.03	336.23	330.49	331.14					
4.1	344.28	326.24	305.84	330.29	341.38	337.49			
4.2	350.18	351.84	369.51	337.54	339.53	321.47	326.13	326.92	329.79
4.3	330.35	339.78	331.62	339.15	332.95				
4.4	352.77	355.13	348.45	339.97	338.46	339.66	337.27	333.18	
4.5	342.51	252.48	332.63	342.71	256.41	327.11	326.77	343.34	
4.6	331.24	335.35	357.52	277.85					
4.7	343.64	336.3	338.43	338.16	337.16	338.04	337.73	340.62	345.99
4.8	343.14	339.35	345.63	341.77	337.73	334.79	337.7	328.72	334.95
4.9	341.82	341.24	339.6	338.79					
5.1	355.59	352.71	348.85	343.07	350.12	344.2	337.6	337.96	338.6
5.2	345.47	343.26	335.53	334.42	323.46	328.68	326.06	326.32	
5.3	340.59	345.1	339.43	335.4	332.57	339.64			
5.4	324.38	330.4	325.71	322.36	319.6	320.95	324.3	318.26	
5.5	337.92	330.67	327.83	326.7					
5.6	344.88	342.45	329.92	324.64					
5.7	358.27	359.84	353.13	351.13	343.04	359.1	366.66	348.6	338.62
5.8	336.79	323.99	318.19	487.94	320.72	465.01			
5.9	348.78	333.65	329.52						
6.1	343.52	333.82	341.23	340.49	330.65	332.41	320.61	329	328.76
6.2	344.36	347.99	320.03	343.46	331.08	339.41	332.1	336.14	302.21
6.3	330.02	341.03	336.38	331.88	329.52	332.79	334.6		
6.4	339.56	325.68	320.55	327.1	323.89				
6.5	344.12	336.8	330.56	324.86	334.12	328.28			
6.6	336.25	336.52	341.69						
6.7	334.74	331.77	327.89	321.63					
6.8	337.97	329.63	333.78	330.63	327.96	328.05			
6.9	349.39	346.24	348.7	330.14	321.7	328.51	329.34	321.2	
7.1	356.49	346.08	344.85	338.07	329.03	323.99	324.79	321.16	
7.2	310	347.38	335.94	331.44	328.07	345.72			

June - Sample Dry Mass (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	343.46	338.74	336.59	330.32	324.16	323.44	321.62	329.08	324
7.4	347.9	352.72	357.2	349.15	336.84	337.17			
7.5	331.52	338.08	323.66	421.29	484.43				
7.6	346.12	341.47	336.18	328.09	332.19	322.85	389.57		
7.7	334.53	338.42	338.8	334.16					
8.1	349.12	351.6	347.23	344.53	346	334.99	336.15	340.67	335.58
8.2	348.97	343.86	344.07	339.14	337.9	330.97	323.06		
8.3	357.18	347.26	343.94	342.92	338.25	340.14	326.3	327.24	319.11
8.4	351.65	339.39	339.49	333.65	329.08	317.88	321.34	329.26	
8.5	345.43	335.95	332.87	332.54	328.98	330.67	333.63	330.77	
8.6	347.13	340.48	338.45	329.67	328.23	334.37	330.36		
8.7	342.93	346.27	36.68						
9.1	344.43	342.84	340.95	338.96	343.08	335.97			
9.2	346.63	347.32	345.91	340.89	342.94	338.98	336.9	343.39	333.92
9.3	350.52	350.44	348.61	341.25					
9.4	331.85	359.15	335.15	336.21	324.85	323	329.2	321.56	385.11
9.5	313.29	346.6	344.53	340.7	339.31	327.43	332.79	326.88	319.98

Table 31: Gravimetric water content calculated for June, by subtracting the wet mass (g) from the dry mass (g) of each sample.

June - Gravimetric Water Content (g)									
Profile	Depth (20 cm)								
	20	40	60	80	100	120	140	160	180
1.1	0.045719	0.047402	0.046585	0.0552	0.0556				
2.2	0.030199	0.049511	0.089025	0.120419	0.113663	0.113522	0.125234		
2.3	0.031676	0.050143	0.061039	0.082377	0.094939	0.089418	0.095593	0.091556	0.125424
2.4	0.034559	0.04336	0.04755	0.053478	0.055785	0.057611			
2.5	0.024202	0.032394	0.038897	0.040628	0.042584	0.043713			
2.6	0.036811	0.056623	0.065732						
3.1	0.015314	0.106625	0.01455	0.032166	0.041746	0.077236	0.098607	0.113073	
3.2	0.076029	0.054632	0.05786	0.067456					
3.3	0.082246	0.075345	0.076579	0.068453					
3.4	0.071554	0.035065	0.042406						
3.5	0.058079	0.04242	0.045243	0.04414					
3.6	0.071537	0.061992							
3.7	0.036065	0.070993	0.08318	0.087425					
4.1	0.029918	0.015602	0.021678	0.031094	0.048245	0.070047			
4.2	0.024159	0.016769	0.020838	0.046869	0.063824	0.091237	0.102505	0.082895	0.080839
4.3	0.070289	0.046324	0.05838	0.05962	0.07851				
4.4	0.014145	0.01177	0.02669	0.053564	0.063405	0.053701	0.078542	0.055556	
4.5	0.055619	0.045152	0.059886	0.067287	0.059982	0.073064	0.07265	0.073542	
4.6	0.058387	0.048844	0.065227	0.064855					
4.7	0.024852	0.041243	0.045475	0.044979	0.04965	0.050142	0.053297	0.054929	0.057574
4.8	0.030046	0.036511	0.038394	0.035375	0.04246	0.053586	0.055908	0.067626	0.068159
4.9	0.026973	0.034726	0.041137	0.046578					
5.1	0.01333	0.0129	0.017916	0.017518	0.021678	0.044974	0.042417	0.042993	0.063113
5.2	0.01951	0.037406	0.050815	0.070959	0.073827	0.092643	0.099951	0.093191	
5.3	0.049913	0.024891	0.04263	0.046899	0.053222	0.054882			
5.4	0.092854	0.085533	0.088883	0.090241	0.098529	0.097024	0.099445	0.101238	
5.5	0.045958	0.062963	0.080926	0.084818					
5.6	0.071126	0.051307	0.081717	0.092194					
5.7	0.005722	0.010421	0.006995	0.01518	0.04533	0.047173	0.057737	0.055536	0.046217
5.8	0.046528	0.093089	0.102235	0.118683	0.110969	0.134126			
5.9	0.031883	0.05248	0.069707						
6.1	0.029227	0.030735	0.03335	0.047344	0.061152	0.066785	0.090577	0.091581	0.086264
6.2	0.018295	0.021983	0.037403	0.027776	0.050532	0.053888	0.068082	0.06765	0.089143
6.3	0.016514	0.034513	0.045514	0.072255	0.06731	0.063764	0.071698		
6.4	0.038992	0.078144	0.092653	0.081321	0.100157				
6.5	0.030803	0.058937	0.083283	0.089238	0.09302	0.090532			
6.6	0.044134	0.047664	0.054055						
6.7	0.062347	0.081412	0.096862	0.098156					
6.8	0.05394	0.065922	0.083708	0.09863	0.092298	0.079896			
6.9	0.045651	0.050861	0.068053	0.084873	0.091949	0.074884	0.109097	0.102522	
7.1	0.024433	0.018782	0.025489	0.047712	0.065222	0.081175	0.082761	0.096369	
7.2	0.023	0.021014	0.057689	0.069907	0.07602	0.076709			

June - Gravimetric Water Content (g) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	0.021633	0.052902	0.061351	0.074806	0.093472	0.104502	0.108171	0.091133	0.108395
7.4	0.02311	0.018513	0.019093	0.030359	0.049014	0.057508			
7.5	0.067568	0.052443	0.082803	0.111396	0.116776				
7.6	0.02268	0.039564	0.052055	0.075711	0.077275	0.099737	0.108812		
7.7	0.031746	0.040482	0.046429	0.050515					
8.1	0.021454	0.01897	0.023126	0.029344	0.012659	0.057255	0.045991	0.052544	0.056022
8.2	0.032324	0.023585	0.024704	0.04591	0.048653	0.064266	0.094162		
8.3	0.01705	0.030813	0.039425	0.035169	0.046238	0.062239	0.080785	0.096474	0.10031
8.4	0.023688	0.036566	0.052991	0.072381	0.076182	0.103372	0.114116	0.107058	
8.5	0.019946	0.039768	0.048157	0.055512	0.067299	0.073457	0.065911	0.070502	
8.6	0.02247	0.03639	0.04819	0.063973	0.066813	0.063971	0.067109		
8.7	0.029131	0.031969	8.61614						
9.1	0.015823	0.030364	0.034639	0.038589	0.043547	0.048397			
9.2	0.02556	0.02764	0.027261	0.026753	0.032396	0.035813	0.040279	0.041789	0.040728
9.3	0.001854	0.023513	0.022805	0.029744					
9.4	0.020009	0.043714	0.052365	0.06142	0.105957	0.086068	0.089064	0.096063	0.121134
9.5	0.020875	0.013762	0.027225	0.034635	0.051457	0.072535	0.078007	0.086607	0.097475

8.3 APPENDIX 3: VOLUMETRIC WATER CONTENT RAW DATA

Table 32: Calculated volumetric water contents ($\text{cm}^3 \bullet \text{cm}^{-3}$) of all samples for January.

January - Volumetric Water Contents (cm ³ •cm ⁻³)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	0.051595	0.060529	0.063874						
2.2	0.10134	0.177449	0.221641	0.240818					
2.3	0.084794	0.096742	0.135404	0.121116					
2.4	0.076368	0.069174	0.084373						
2.5	0.056477	0.057276	0.068693						
2.6	0.03908	0.031059	0.065428	0.06409					
3.1	0.067297	0.089059	0.151813	0.143534	0.163173				
3.2	0.09296	0.074647	0.102649	0.133427	0.140603				
3.3	0.094046	0.108979	0.163025	0.128931	0.113287				
3.4	0.072371	0.059576	0.066186	0.080709					
3.5	0.069685	0.077362	0.077448						
3.6		0.081328							
3.7	0.10304	0.129074	0.149522						
4.1	0.010237	0.015979	0.022413	0.095906		0.071255	0.101793	0.124906	
4.2	0.036319	0.067031	0.127615	0.125141	0.118352	0.122703	0.129418		
4.3	0.092765	0.071207	0.080362	0.093368	0.098785				
4.4	0.079876	0.079882	0.114576	0.117488					
4.5	0.066934	0.100457	0.053387	0.067841	0.074407	0.105353	0.160761		
4.6	0.046904	0.02036	0.067898	0.077669	0.104928				
4.7	0.008494	0.027517	0.068866	0.117759	0.141192				
4.8	0.079086	0.022544							
4.9	0.064007		0.041927						
5.1		0.077942	0.115502	0.138765	0.149085				
5.2	0.049729	0.050648	0.069376	0.099021	0.109878	0.128814	0.136529		
5.3	0.059101	0.046922	0.059704	0.072958	0.073274	0.081365	0.078099		
5.4	0.124537	0.13285	0.140909	0.147685	0.163966				
5.5	0.081029	0.125321	0.132934						
5.6	0.099675	0.115543	0.131676	0.14312					
5.7	0.121768	0.110285	0.142713						
5.8	0.110802		0.095316						
5.9	0.059212	0.061066	0.053896						
6.1	0.078911	0.067855	0.105774	0.11371	0.119992	0.131639			
6.2	0.043838	0.052209	0.073708	0.083809	0.094153	0.119758			
6.3	0.051344	0.055549	0.110336	0.113062	0.129206	0.132262	0.1939		
6.4	0.106775	0.111253	0.138702	0.143264					
6.5	0.079513	0.120176	11.81947	0.157686	0.17158				
6.6	0.109137	0.110856	0.112604	0.137597					
6.7	0.119236	0.12972		0.130578					
6.8	0.091424	0.105573	0.155231	0.132393	0.160026	0.222405			

January - Volumetric Water Contents (cm³•cm⁻³) (continued)

Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
6.9	0.030921	0.061005	0.094363	0.126361	0.117632				
7.1	0.074164	0.035045	0.073935	0.093791	0.101497	0.148633	0.18952		
7.2	0.032843	0.077083	0.099355	0.104437	0.129397	0.088002			
7.3	0.08159		0.109955	0.163798	0.147814	0.059916	0.646368		
7.4		0.113218		0.10582	0.133005	0.181665			
7.5	0.141131	0.122746	0.170965	0.167219					
7.6	0.083028	0.113595	0.113154	0.155899	0.1432				
7.7	0.023716	0.060365		0.074106					
8.1	0.016971	0.038389	0.033406	0.054511	0.077817	0.072061	0.082789	0.122254	0.122304
8.2	0.039344	0.061564	0.073943	0.086307	0.10535	0.117516	0.135426	0.151784	
8.3	0.029137	0.04026	0.101951	0.129733	0.131668	0.144688			
8.4	0.050348	0.067053	0.095012	0.107204	0.155619	0.157133		0.182989	
8.5	0.070974	0.097913	0.115087	0.134064	0.122402				
8.6	0.016681	0.029062	0.05768	0.078783	0.101766	0.125733	0.124102		
8.7	0.012368	0.02291	0.697227						
9.1	0.032899	0.027545	0.028676	0.072328	0.05481	0.066746	0.10162		
9.2	0.018147	0.01396	0.044533	0.183161		0.062599	0.07624	0.066206	
9.3	0.0098	0.008642	0.01485						
9.4	0.022205	0.047604	0.090357	0.088428	0.139583	0.156148	0.183553	0.155005	
9.5	0.010056	0.039106	0.061042	0.092667	0.140712	0.14547	0.125738		

Table 33: Calculated volumetric water contents ($\text{cm}^3 \bullet \text{cm}^{-3}$) of all samples for March.

March - Volumetric Water Contents ($\text{cm}^3 \bullet \text{cm}^{-3}$)

Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	0.062593	0.065303	0.075332	0.081368	0.08582				
2.2	0.03207	0.040924	0.063745	0.100217	0.203609				
2.3	0.073957	0.080923	0.090549	0.104538	0.108709	0.145771	0.168635	0.173043	
2.4	0.071804	0.068302	0.072541	0.083701	0.081707				
2.5	0.057111	0.048153	0.051302	0.055063					
2.6	0.06604	0.059696	0.07525	0.101654					
3.1	0.064914	0.07632	0.09437	0.117554	0.150699	0.161124			
3.2	0.094482	0.084592	0.092692	0.109666	0.105594				
3.3	0.083661	0.090871	0.099066	0.109681	0.115802				
3.4	0.085305	0.067267	0.061503	0.074566					
3.5	0.056169	0.046067		0.069729					
3.6	0.081894	0.070469							
3.7	0.08146	0.101225	0.521246	0.145444	0.146163				
4.1	0.050023	0.029317	0.057934	0.057921	0.056649	0.071949	0.085821	0.129252	
4.2	0.050772	0.062379	0.060953	0.112079	0.115549		0.117347	0.144379	0.175443
4.3	0.06225	0.059873	0.071631	0.075105	0.089039	0.076408	0.082367		
4.4	0.035297	0.033252	0.04937	0.055897	0.072116				
4.5	0.083958	0.079866	0.089155	0.143041	0.083432	0.130219	0.171516		
4.6	0.084111	0.093055	0.109028	0.127306	0.134623				
4.7	0.081486	0.069327	0.083849	0.101731	0.126164				
4.8	0.082847	0.065907	0.063884						
4.9		0.033426	0.035553						
5.1	0.046258	0.045023	0.085471	0.10757	0.11266	0.111582	0.102235	0.14372	0.136636
5.2	0.045573	0.034045	0.060891	0.082956	0.108611	0.122771	0.12571	0.126339	0.146621
5.3	0.058682	0.037769	0.058269	0.044902	0.07316	0.089553	0.086076		
5.4	0.114174	0.122468	0.124452	0.139661	0.146991				
5.5	0.06818	0.067932	0.079558						
5.6	0.11109	0.100112	0.089584	0.122157					
5.7	0.034767	0.035953	0.066412						
5.8	0.102599	0.082149	0.079625						
5.9	0.076041	0.059535	0.060745						
6.1	0.074513	0.076834	0.087012	0.102329	0.102427	0.11492	0.114937	0.13455	0.134188
6.2	0.027082	0.056552	0.064427	0.089107	0.088448	0.099101	0.108895	0.111317	
6.3	0.050348	0.072442	0.084042	0.097035	0.107976	0.110882			
6.4	0.112327	0.106838	0.111758	0.101717					
6.5	0.049221	0.084386	0.139449	0.151997	0.130726	0.141515			
6.6	0.103452	0.093349	0.095674	0.129685					
6.7	0.074438	0.080376	0.077689	0.107185					
6.8	0.115506	0.087072	0.117746	0.108836	0.137664	0.157588	0.155859		
6.9	0.054351	0.060626	0.062237	0.078847	0.094858	0.117732			
7.1	0.025896	0.04408	0.076706	0.109187	0.123034	0.123798	0.130111	0.155094	
7.2	0.021428	0.021914	0.060403	0.111091	0.129625	0.138091			

March - Volumetric Water Contents (cm ³ •cm ⁻³) (continued)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	0.026498	0.052989	0.123013	0.179028	0.162979	0.208938			
7.4	0.030305	0.097987	0.109246						
7.5	0.104711	0.120239	0.152904	0.16214	0.175343				
7.6	0.052902	0.096641	0.1375	0.2195	0.086426				
7.7	0.024619	0.035254	0.056872						
8.1	0.011396	0.010646	0.028591	0.037492	0.056886	0.051049	0.078867	0.084247	0.09102
8.2	0.012796	0.021696	0.033442	0.063234	0.077223	0.058257	0.074599	0.038311	0.115878
8.3	0.01826	0.036637	0.075473	0.116919	0.167648	0.144204	0.172241	0.192054	
8.4	0.03526	0.04699	0.077011	0.127268	0.192009	0.15191	0.183866	0.125288	
8.5	0.035113	0.067419	0.088727	0.118724	0.090145				
8.6	0.01804	0.030532	0.046438	0.048948	0.068686	0.086352	0.084502		
8.7	0.018705	0.018675	0.04314						
9.1	0.019822	0.016983	0.020213	0.025416	0.027894	0.028007	0.020172		
9.2	0.013552	0.011142	0.004646	0.015003	0.01044	0.021302	0.024437	0.022631	
9.3	0.018956	0.030936	0.042598						
9.4	0.017037	0.014996	0.03599	0.066575	0.067058	0.065214	0.073512	0.093768	0.107168
9.5	0.008829	0.015228	0.06353	0.082763	0.07558	0.067761			

Table 34: Calculated volumetric water contents ($\text{cm}^3 \bullet \text{cm}^{-3}$) of all samples for June.

June - Volumetric Water Contents ($\text{cm}^3 \bullet \text{cm}^{-3}$)									
Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
1.1	0.057888	0.059274	0.062153	0.07658	0.083637				
2.2	0.040838	0.06772	0.127434	0.167059	0.147598				
2.3	0.040274	0.06207	0.0783	0.097191	0.120914	0.157568	0.180205	0.178225	
2.4	0.047588	0.053504	0.061059	0.078421	0.080303				
2.5	0.033135	0.040155	0.050254	0.054959					
2.6	0.044895	0.068346	0.082425						
3.1	0.019524	0.132634	0.019837	0.046519	0.061273	0.108284			
3.2	0.101856	0.061993	0.070216	0.090624					
3.3	0.115492	0.102155	0.114987	0.094966					
3.4	0.104896	0.042067	0.052068						
3.5	0.083216	0.051314	0.057799	0.055176					
3.6	0.105868	0.077088							
3.7	0.047831	0.10156	0.116617	0.142264					
4.1	0.03843	0.018388	0.026985	0.036726	0.05425	0.086281			
4.2	0.024789	0.019944	0.027115	0.057121	0.077535	0.114765	0.121602	0.114228	0.141997
4.3	0.106178	0.053837	0.068803	0.072738	0.093035				
4.4	0.016884	0.014847	0.037811	0.077609	0.102129				
4.5	0.077903	0.053739	0.074703	0.077737	0.062328	0.109017	0.12487		
4.6	0.07955	0.061142	0.084615	0.092576					
4.7	0.034135	0.053122	0.065705	0.073316	0.078747				
4.8	0.043642	0.042998	0.048596						
4.9	0.039918	0.045094	0.044994						
5.1	0.017497	0.015588	0.022419	0.022887	0.029038	0.058934	0.055864	0.069547	0.098373
5.2	0.024243	0.038192	0.05838	0.093922	0.089976	0.119693	0.130319	0.125198	
5.3	0.063548	0.028682	0.048812	0.053881	0.057127	0.06284			
5.4	0.121514	0.115628	0.120117	0.138811	0.153576				
5.5	0.063962	0.080878	0.10915						
5.6	0.089934	0.0606	0.110867	0.130983					
5.7	0.007173	0.013063	0.009685						
5.8	0.068543	0.123337	0.126062						
5.9	0.045054	0.067114	0.086136						
6.1	0.041119	0.03662	0.041514	0.061229	0.078525	0.083833	0.118813	0.133062	0.130699
6.2	0.025299	0.026069	0.046755	0.035704	0.059749	0.066939	0.091736	0.099843	
6.3	0.018337	0.037324	0.056656	0.096211	0.091053	0.089652	0.118354		
6.4	0.052349	0.091961	0.116304	0.11914					
6.5	0.031166	0.072776	0.10476	0.131704	0.123615	0.126805			
6.6	0.053941	0.060872	0.064125						
6.7	0.087022	0.113089	0.124762	0.139979					
6.8	0.068556	0.080943	0.120498	0.133551	0.13834	0.127705			
6.9	0.059721	0.065711	0.091967	0.111443	0.117588	0.109104			
7.1	0.033711	0.02224	0.031297	0.064162	0.081018	0.117289	0.118913	0.163088	
7.2	0.02852	0.021961	0.06354	0.09253	0.116213	0.11612			

June - Volumetric Water Contents (cm³•cm⁻³) (continued)

Profile	Depth (cm)								
	20	40	60	80	100	120	140	160	180
7.3	0.028576	0.066313	0.076851	0.105678	0.134177	0.178304	0.18291		
7.4	0.028175	0.021978	0.023543	0.037277	0.078613	0.107756			
7.5	0.084256	0.068423	0.116975	0.169686	0.200876				
7.6	0.028697	0.047413	0.064935	0.108986	0.10597				
7.7	0.039241	0.047849	0.057189	0.065131					
8.1	0.026753	0.021762	0.028275	0.036988	0.016272	0.071945	0.058816	0.082257	0.087321
8.2	0.038471	0.02642	0.027906	0.048929	0.051667	0.072759	0.120666		
8.3	0.018656	0.030362	0.049129	0.044791	0.060408	0.086511	0.125366	0.14108	
8.4	0.028142	0.039357	0.067073	0.097049	0.106705	0.138466	0.178182	0.158148	
8.5	0.025334	0.046149	0.063042	0.070263	0.085712				
8.6	0.028657	0.042667	0.057543	0.091317	0.113348	0.12508	0.12156		
8.7	0.038931	0.039129	0.17674						
9.1	0.021076	0.034104	0.041855	0.046278	0.052167	0.059299			
9.2	0.032375	0.029739	0.026748	0.036759	0.049084	0.057489	0.070187	0.068406	
9.3	0.002606	0.028382	0.026994						
9.4	0.026475	0.05118	0.06307	0.080324	0.14305	0.123202	0.131206	0.147374	0.178287
9.5	0.028063	0.016314	0.032615	0.044338	0.069677	0.11197	0.116393		

8.4 APPENDIX 4: NEUTRON PROBE CALIBRATION AND RAW DATA

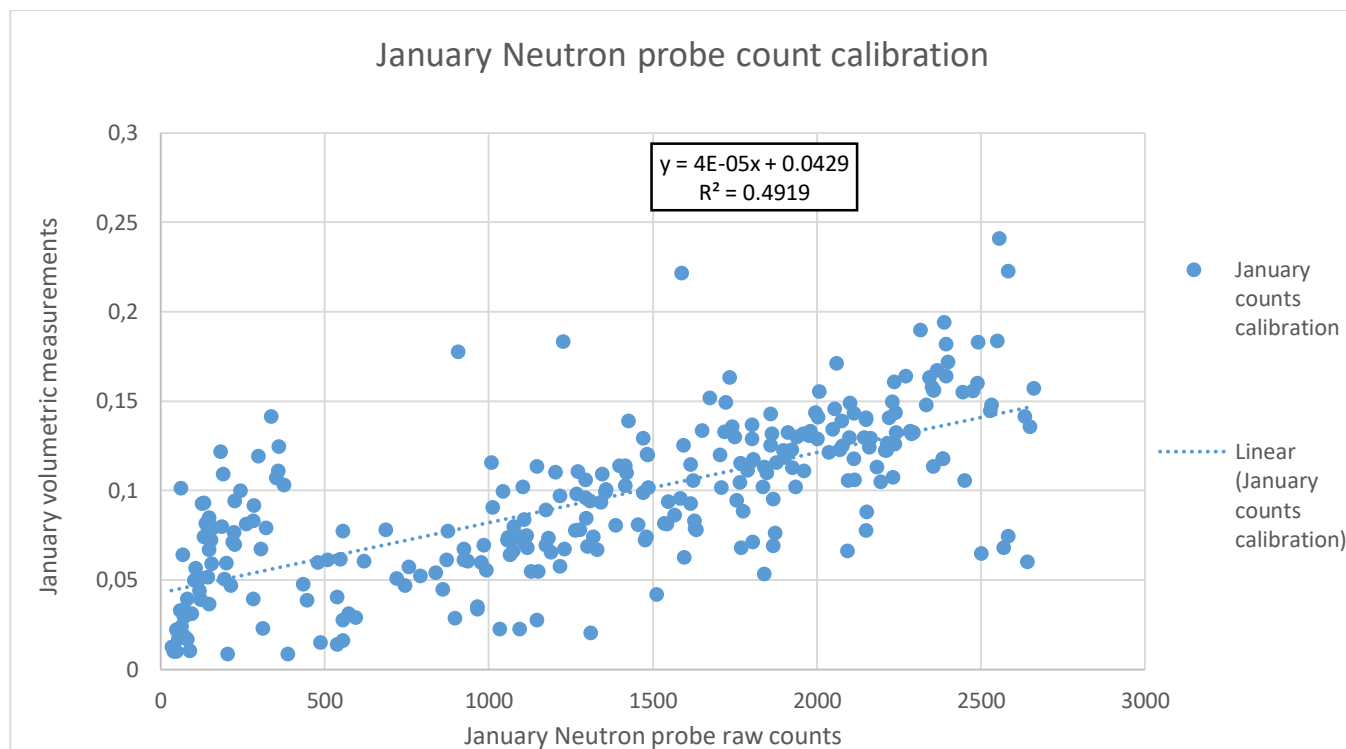


Figure 28: Scatterplot of the January volumetric measurements vs the January Neutron probe raw counts to give a linear trend line. This equation was used to calculate the calibrated volumetric Neutron probe measurements for the month of January.

Table 35: Calibrated Neutron probe volumetric measurements for the month of January, by using the calculated equation.

January Probe Calibrated Volumetric Measurements							
Profile	Depth (cm)						
	20	40	60	80	100	120	140
1.1	0.0475	0.08026	0.08546				
2.2	0.04534	0.0791	0.10634	0.14506			
2.3	0.04878	0.0915	0.1125	0.1243			
2.4	0.05182	0.08226	0.0947				
2.5	0.04714	0.07314	0.09486				
2.6	0.0477	0.06578	0.09042				
3.1	0.0551	0.08982	0.10978	0.1227	0.13658		
3.2	0.0481	0.0875	0.09946	0.1089	0.13166		
3.3	0.0519	0.09666	0.11222	0.12294	0.13702		
3.4	0.04898	0.06202	0.08586	0.10106			
3.5	0.05186	0.07786	0.09342				
3.6		0.10454					
3.7	0.0579	0.1017	0.13206				
4.1	0.04642	0.06506	0.08418	0.09466		0.11502	0.1203
4.2	0.04878	0.07986		0.10662	0.1189	0.11978	0.12682
4.3	0.04786	0.08718	0.0983	0.0965	0.1017		

January Probe Calibrated Volumetric Measurements (continued)								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
4.4	0.05034	0.08594	0.10742	0.11514				
4.5	0.04878	0.09718	0.11646	0.14566	0.14618	0.1409	0.1323	
4.6	0.05142	0.0953	0.11366	0.12882	0.13066			
4.7	0.05102	0.08874	0.1175	0.12738	0.14818			
4.8	0.04918	0.08662						
4.9	0.04554		0.1033					
5.1		0.0703	0.08318	0.0999	0.11174			
5.2	0.04694	0.07162	0.08982	0.0971	0.09962	0.11494	0.11498	
5.3	0.0491	0.07266	0.08194	0.0857	0.09014	0.10426	0.10818	
5.4	0.05726	0.11158	0.12298	0.13622	0.13862			
5.5	0.0533	0.11722	0.12202					
5.6	0.05258	0.11794	0.12118	0.12738				
5.7	0.05018	0.09102	0.11718					
5.8	0.05718		0.10618					
5.9	0.05082	0.06318	0.07642					
6.1	0.05566	0.08758	0.09466	0.09878	0.11102	0.11734		
6.2	0.04758	0.0745	0.08518	0.08714	0.09518	0.10226		
6.3	0.04862	0.08258	0.0937	0.11646	0.12942	0.13462	0.13834	
6.4	0.05694	0.11442	0.1259	0.13242				
6.5	0.04858	0.10218	0.1193	0.13686	0.13886			
6.6	0.0505	0.12126	0.1199					
6.7	0.05474	0.11282		0.1219				
6.8	0.05422	0.10778	0.12314	0.13254	0.14242	0.14618		
6.9	0.04662	0.07982	0.1131	0.13146	0.13822			
7.1	0.04814	0.08146	0.09562	0.1047	0.11118	0.1269	0.13546	
7.2	0.04578	0.06506	0.08462	0.11346	0.12862	0.12894		
7.3	0.04834		0.11674	0.13366	0.14414	0.1485	0.1429	
7.4		0.08874		0.12746	0.13422	0.13862		
7.5	0.0563	0.12566	0.12522	0.13754				
7.6	0.0541	0.09946	0.13014	0.1371				
7.7	0.04538	0.06766		0.1021				
8.1	0.04502	0.0607	0.08146	0.08802	0.09398	0.10194	0.10794	0.11878
8.2	0.04606	0.06474	0.08702	0.1055	0.12666	0.13818	0.14886	
8.3	0.0457	0.06434	0.08702	0.12038	0.13442	0.14402		
8.4	0.05066	0.0921	0.11754	0.1321	0.1419	0.14934		0.14254
8.5	0.05166	0.09354	0.11354	0.12482	0.13122			
8.6	0.04606	0.06666	0.09154	0.10802	0.11626	0.13238	0.12922	
8.7	0.04422	0.05534						
9.1	0.04522	0.06506	0.0787	0.08514	0.08886	0.09606	0.10234	
9.2	0.04582	0.06438	0.07722	0.09194		0.10666	0.11774	0.12658
9.3	0.04442	0.05838	0.0623					
9.4	0.04478	0.06022	0.08334	0.11386	0.12882	0.13702	0.14482	0.14062
9.5	0.04478	0.0541	0.0777	0.10746	0.12882	0.12502	0.13186	

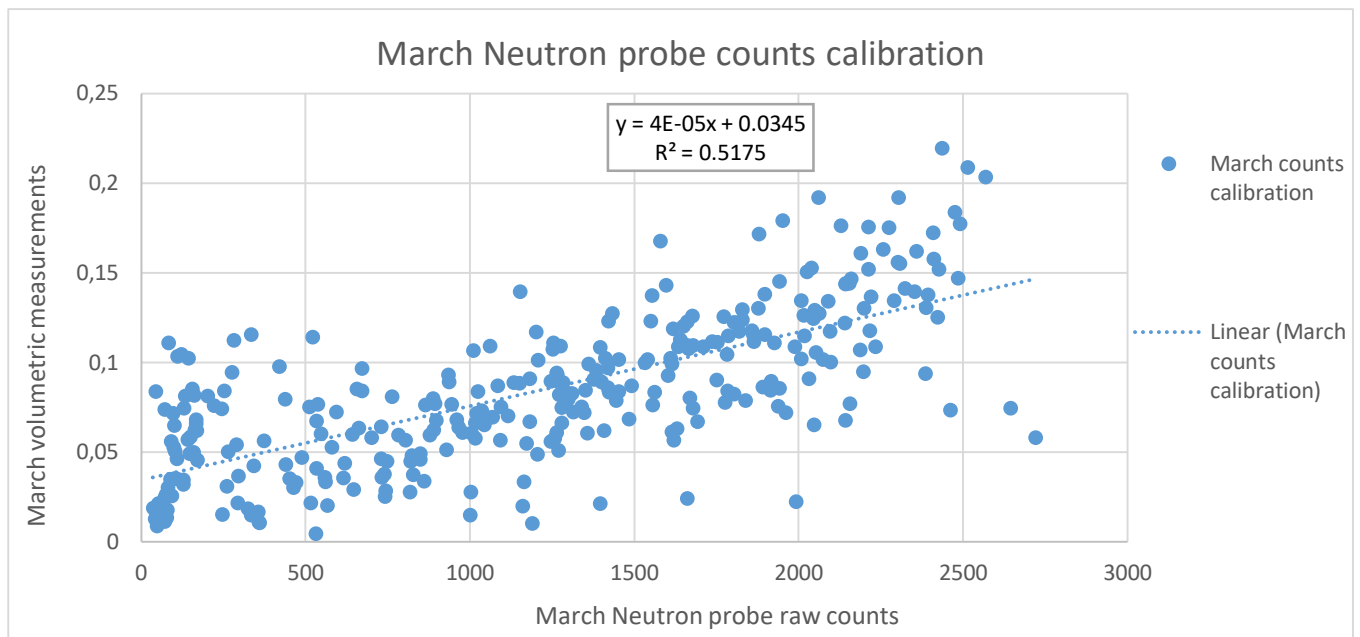


Figure 29: Scatterplot of the March volumetric measurements vs the March Neutron probe raw counts to give a linear trend line. This equation was used to calculate the calibrated volumetric Neutron probe measurements for the month of March.

Table 36: Calibrated Neutron probe volumetric measurements for the month of March, by using the calculated equation.

March Probe Calibrated Volumetric Measurements								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
1.1	0.04102	0.07622	0.08806					
2.2	0.03962	0.05582	0.0731	0.11838	0.13726			
2.3	0.0373	0.06498	0.08958	0.10574	0.11398			
2.4	0.03838	0.07286	0.08706	0.09142				
2.5	0.04014	0.06742	0.07166	0.08138				
2.6	0.04118	0.06574	0.07822	0.09262				
3.1	0.03854	0.06906	0.08506	0.10726	0.11546	0.12206		
3.2	0.0455	0.0885	0.09862	0.10094	0.11658			
3.3	0.04066	0.08178	0.09902	0.10166	0.10898			
3.4	0.04066	0.08178	0.09902	0.10166				
3.5	0.03814	0.06846		0.07726				
3.6	0.04094	0.07914						
3.7	0.04258	0.08278	0.11026	0.11218				
4.1	0.04082	0.06034	0.07514	0.08478	0.09926	0.1129	0.11218	0.11646
4.2	0.03858	0.07006	0.08502	0.10014	0.11034		0.1183	0.12062
4.3	0.04122	0.06018	0.07526	0.08562	0.08582	0.0967	0.10662	
4.4	0.03874	0.05334	0.06842	0.0843	0.08834			
4.5	0.03626	0.06998	0.09046	0.09834	0.09698	0.10954	0.10962	
4.6	0.04462	0.08514	0.1029	0.11694	0.1261			
4.7	0.03982	0.07674	0.09262	0.0961	0.10154			

March Probe Calibrated Volumetric Measurements (continued)								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
4.8								
4.9		0.0569	0.0591					
5.1	0.03878	0.06438	0.06074	0.08454	0.10006	0.10906	0.11482	0.12018
5.2	0.04134	0.06886	0.07358	0.08642	0.09034	0.1009	0.10538	0.1151
5.3	0.04042	0.06406	0.0625	0.06722	0.0759	0.0843	0.09126	
5.4	0.05534	0.10658	0.11626	0.12858	0.1339			
5.5	0.04114	0.07038	0.05198					
5.6	0.03782	0.09578	0.1111	0.1201				
5.7	0.03962	0.05682	0.07514					
5.8	0.04018	0.0853	0.08642					
5.9	0.0433	0.06958	0.08874					
6.1	0.0397	0.05594	0.07786	0.09098	0.0989	0.1059	0.11518	0.11478
6.2	0.03778	0.04938	0.0637	0.07194	0.0805	0.0889	0.09982	0.10462
6.3	0.04502	0.05822	0.07542	0.09122	0.10106	0.1115		
6.4	0.04578	0.07486	0.10394	0.11746				
6.5	0.04034	0.0613	0.08058	0.12294	0.12998	0.12742		
6.6	0.03886	0.07182	0.08986					
6.7	0.04426	0.10126	0.1055	0.12198				
6.8	0.04782	0.09418	0.10878	0.12386	0.13026	0.1309	0.12654	
6.9	0.04606	0.07466	0.09078	0.10802	0.12238	0.1231		
7.1	0.03818	0.05922	0.07226	0.0855	0.0965	0.10766	0.12246	0.12678
7.2	0.03658	0.04618	0.05638	0.08466	0.10766	0.11038		
7.3	0.0375	0.05766	0.0913	0.1125	0.12478	0.13506		
7.4	0.0377	0.0513	0.0769					
7.5	0.03938	0.10046	0.11602	0.12878	0.1255			
7.6	0.03846	0.0613	0.09666	0.13194				
7.7	0.0373	0.0525	0.06666					
8.1	0.03734	0.0489	0.06418	0.06758	0.07814	0.08522	0.0923	0.10586
8.2	0.03618	0.0551	0.08102	0.0997	0.1207	0.1433	0.1403	
8.3	0.03722	0.04626	0.05498	0.08254	0.09766	0.12022	0.13082	0.12666
8.4	0.03854	0.05402	0.07022	0.09182	0.11686	0.13154	0.13346	0.13138
8.5	0.03802	0.05578	0.07978	0.09922	0.10454			
8.6	0.03762	0.05298	0.0637	0.08266	0.09386	0.1101	0.11106	
8.7	0.03738	0.04746	0.0521					
9.1	0.0371	0.04874	0.05714	0.06414	0.06718	0.07458	0.08086	
9.2	0.03754	0.04878	0.05574	0.07454	0.08206	0.0903	0.1009	0.11418
9.3	0.0359	0.04486	0.04818					
9.4	0.03622	0.04786	0.06378	0.08562	0.10218	0.11638	0.13294	0.1299
9.5	0.03642	0.04438	0.06098	0.0869	0.11202	0.12018		

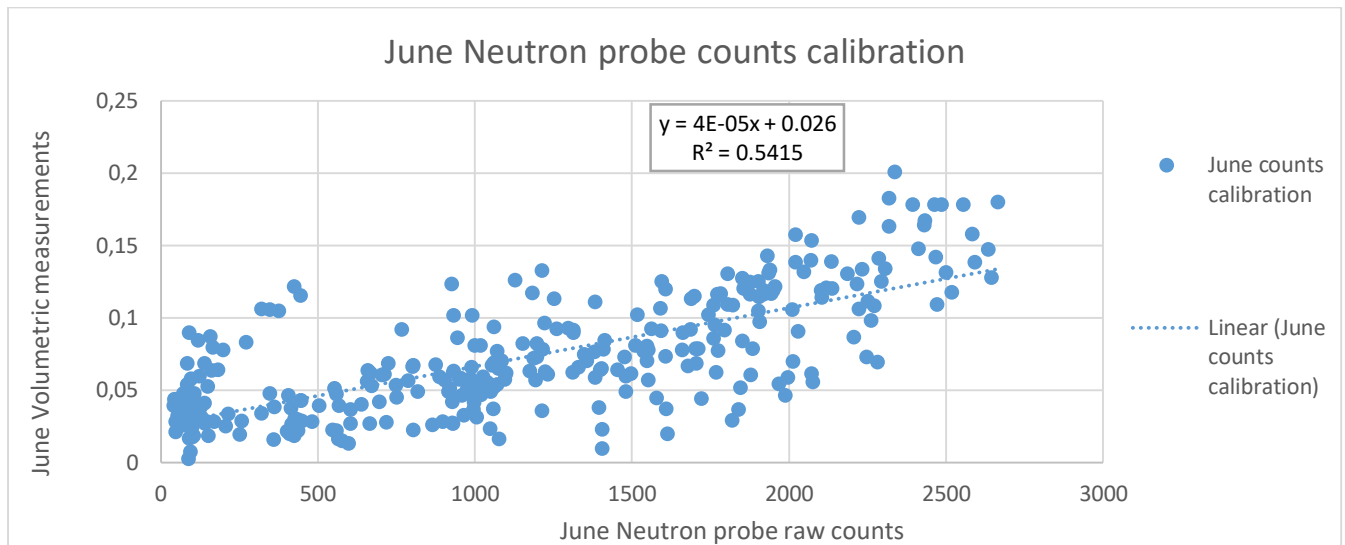


Figure 30: Scatterplot of the June volumetric measurements vs the June Neutron probe raw counts to give a linear trend line. This equation was used to calculate the calibrated volumetric Neutron probe measurements for the month of June.

Table 37: Table 38: Calibrated Neutron probe volumetric measurements for the month of June, by using the calculated equation.

June Probe Calibrated Volumetric Measurements								
Profile	Depth (20cm)							
	20	40	60	80	100	120	140	160
1.1	0.02984	0.06148	0.07848	0.08124				
2.2	0.02984	0.061	0.10008	0.12328	0.12248			
2.3	0.029	0.05272	0.0824	0.10224	0.11072	0.1068	0.13264	0.1218
2.4	0.03028	0.05596	0.07532	0.0746				
2.5	0.02944	0.05152	0.065					
2.6	0.03012	0.055	0.07392					
3.1	0.03608	0.07456	0.09056	0.10556	0.10884	0.11688		
3.2	0.06564	0.06996	0.08024	0.10716				
3.3	0.0438	0.08672	0.09396	0.09656				
3.4	0.041	0.06312	0.06844					
3.5	0.03684	0.0628	0.06544	0.06764				
3.6	0.03992	0.06884						
3.7	0.02888	0.06328	0.10376					
4.1	0.03108	0.04296	0.0632	0.0996	0.10472			
4.2	0.03	0.0424	0.06316	0.08808	0.097	0.10216	0.10424	0.11016
4.3	0.03884	0.06616	0.0684	0.07388	0.07792			
4.4	0.02964	0.04912	0.08184	0.08812	0.09576			
4.5	0.03392	0.06724	0.07996	0.0924	0.09672	0.09644		
4.6	0.0326	0.06988	0.08252	0.08852				
4.7	0.03004	0.05288	0.0792	0.09032	0.09412			
4.8	0.02776	0.0438	0.06532					
4.9	0.03048	0.05604						
5.1	0.03	0.04036	0.05816	0.08224	0.09876	0.10588	0.109	0.11724
5.2	0.02968	0.04048	0.06416	0.06844	0.07856	0.09028	0.0982	0.10212

June Probe Calibrated Volumetric Measurements (continued)								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
5.3	0.03244	0.044	0.05872	0.06884	0.07376	0.07496		
5.4	0.04296	0.09724	0.1002	0.11144	0.10888			
5.5	0.03332	0.066	0.09816					
5.6	0.0296	0.0542	0.08132	0.10344				
5.7	0.0298	0.04996	0.08224					
5.8	0.03156	0.06304	0.07116					
5.9	0.02956	0.05816	0.06376					
6.1	0.0316	0.0502	0.06592	0.08588	0.09444	0.10004	0.10396	0.10356
6.2	0.03424	0.06064	0.0668	0.07456	0.08524	0.09316	0.09776	
6.3	0.03208	0.0426	0.05752	0.07484	0.08968	0.09252		
6.4	0.032	0.05668	0.09688	0.10272				
6.5	0.0312	0.08508	0.10208	0.10788				
6.6	0.02936	0.05452	0.08196					
6.7	0.03232	0.07608	0.10108	0.1088				
6.8	0.0294	0.06672	0.11148	0.11528	0.12964	0.1318		
6.9	0.03092	0.06556	0.09344	0.11608	0.12672	0.12488		
7.1	0.0346	0.04792	0.0662	0.0842	0.08644	0.07336	0.11008	0.11876
7.2	0.02996	0.04348	0.05236	0.07644	0.10104	0.10272		
7.3	0.03632	0.05808	0.08752	0.10644	0.11824	0.1254	0.11876	
7.4	0.03188	0.04836	0.06796	0.09036	0.1014			
7.5	0.03072	0.09416	0.09728	0.11492	0.11944			
7.6	0.0294	0.04836	0.08212	0.09888	0.11492			
7.7	0.02768	0.03988	0.06212	0.06904				
8.1	0.03164	0.04212	0.06192	0.06836	0.06908	0.07352	0.08132	0.07208
8.2	0.031	0.04264	0.05476	0.0852	0.09984	0.11592		
8.3	0.0302	0.04304	0.06268	0.08916	0.10116	0.11428	0.11776	0.11744
8.4	0.03276	0.04868	0.0682		0.08964	0.10684	0.12452	0.12932
8.5	0.0286	0.04228	0.073	0.08796	0.09644			
8.6	0.0286	0.04388	0.06404	0.07852	0.09356	0.08976		
8.7	0.02916	0.0462	0.05232					
9.1	0.02792	0.03884	0.0538	0.06436	0.06548	0.06708		
9.2	0.02816	0.04348	0.05264	0.06584	0.06804	0.06984	0.0694	
9.3	0.02956	0.04524	0.0502					
9.4	0.02852	0.04812	0.06328	0.08792	0.10324	0.11464	0.12604	0.1314
9.5	0.02792	0.0486	0.06456	0.09488	0.10648			

8.5 APPENDIX 5: DIVINER CALIBRATION AND RAW DATA

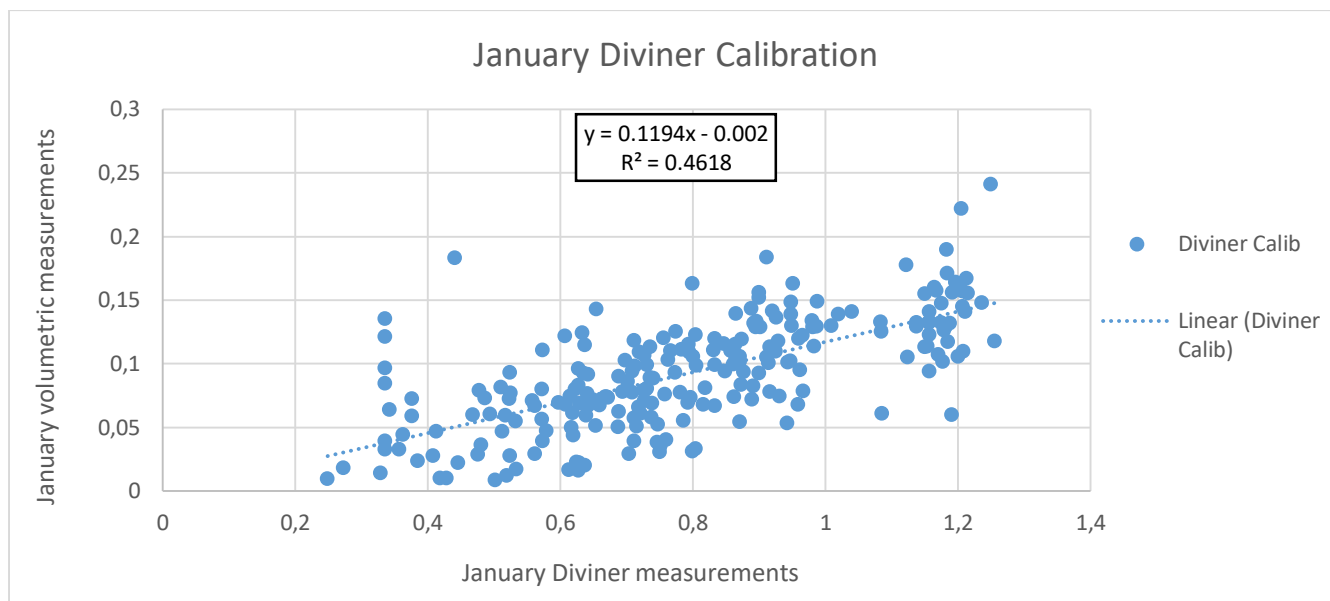


Figure 31: Scatterplot of the January volumetric measurements vs the January Diviner raw measurements to give a linear trend line. This equation was used to calculate the calibrated volumetric Diviner measurements for the month of January.

Table 38: January calibrated volumetric measurements for the Diviner, using the calculated equation.

January - Diviner Calibrated Volumetric Measurements							
Profile	Depth (cm)						
	20	40	60	80	100	120	140
1.1							
2.2	0.11058	0.13190	0.14183	0.14721			
2.3	0.03799	0.03799	0.03799	0.03799			
2.4	0.07442	0.08616					
2.5	0.06628	0.08286					
2.6	0.06641	0.09340					
3.1	0.07665	0.08579	0.10545	0.10403	0.11150		
3.2	0.06053	0.07138	0.08132	0.10497			
3.3	0.08261	0.09278	0.09340	0.10485			
3.4	0.04288	0.07429	0.08376				
3.5	0.06924	0.08261	0.09117				
3.6							
3.7	0.08906	0.11505					
4.1	0.04797	0.07284	0.07297	0.07284		0.07561	
4.2	0.05537	0.07456	0.08376	0.09043	0.08286	0.09402	0.13381
4.3	0.07376	0.08477	0.08515	0.09030	0.09414		
4.4	0.06628	0.07231	0.07403				
4.5	0.06507	0.10716	0.11046	0.11240	0.10913	0.10676	
4.6	0.05915	0.07403	0.07055				
4.7	0.05784	0.06054	0.07309	0.10882	0.10779		

January - Diviner Calibrated Volumetric Measurements (continued)								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
4.8	0.05501	0.07253						
4.9	0.03885							
5.1		0.08081	0.10117	0.11116	0.11585			
5.2	0.07165	0.08337	0.09254	0.09743	0.10838	0.10568	0.10849	
5.3	0.04288	0.04725	0.05382	0.05608	0.07822			
5.4	0.07350	0.12727	0.14255	0.13832				
5.5	0.09573	0.12738	0.13623					
5.6	0.10081	0.09900						
5.7	0.07045	0.08943	0.07613					
5.8	0.06641							
5.9	0.05970							
6.1	0.08464	0.09536	0.10189	0.11528	0.11254	0.10450		
6.2	0.07191	0.08717	0.09303	0.10212	0.09925	0.09743		
6.3	0.07600	0.09180	0.10033	0.10733	0.11573	0.13822		
6.4	0.08477	0.09142	0.11967					
6.5	0.08503	0.08818	0.13381	0.13738				
6.6	0.08388	0.09719						
6.7	0.10224	0.11127						
6.8	0.07456	0.09352	0.13529	0.13592	0.13697			
6.9	0.08755	0.12760	0.13613	0.13874	0.14791			
7.1	0.07770	0.08768	0.10093	0.10260	0.10189	0.11116	0.13915	
7.2	0.03799	0.06067	0.08515	0.10129	0.13905			
7.3	0.05887		0.14224	0.14081	0.14560	0.14008	0.13895	
7.4		0.08579		0.14132				
7.5	0.13613	0.13613	0.13936	0.14276				
7.6	0.07284	0.13571	0.13529	0.14029				
7.7	0.04391	0.05692						
8.1	0.06163	0.08705	0.09402	0.10189	0.10733	0.10415	0.10438	0.11323
8.2	0.03799	0.07178	0.07796	0.08171	0.13222	0.13946		
8.3	0.06506	0.08868	0.11104	0.11844	0.13978	0.14214		
8.4	0.08003	0.09743	0.11277	0.13770	0.14306	0.14214		
8.5	0.06451	0.08299	0.09266	0.11494				
8.6	0.07111	0.08196	0.08604	0.11334	0.13853			
8.7	0.05998							
9.1	0.04058	0.04665	0.05470	0.06040	0.06158			
9.2	0.03054	0.03721	0.04123	0.05061		0.08010	0.08839	
9.3	0.02769							
9.4	0.05112	0.06711	0.08010	0.08631	0.10128	0.10537	0.10680	
9.5	0.04912	0.08286	0.08401	0.10545	0.12212			

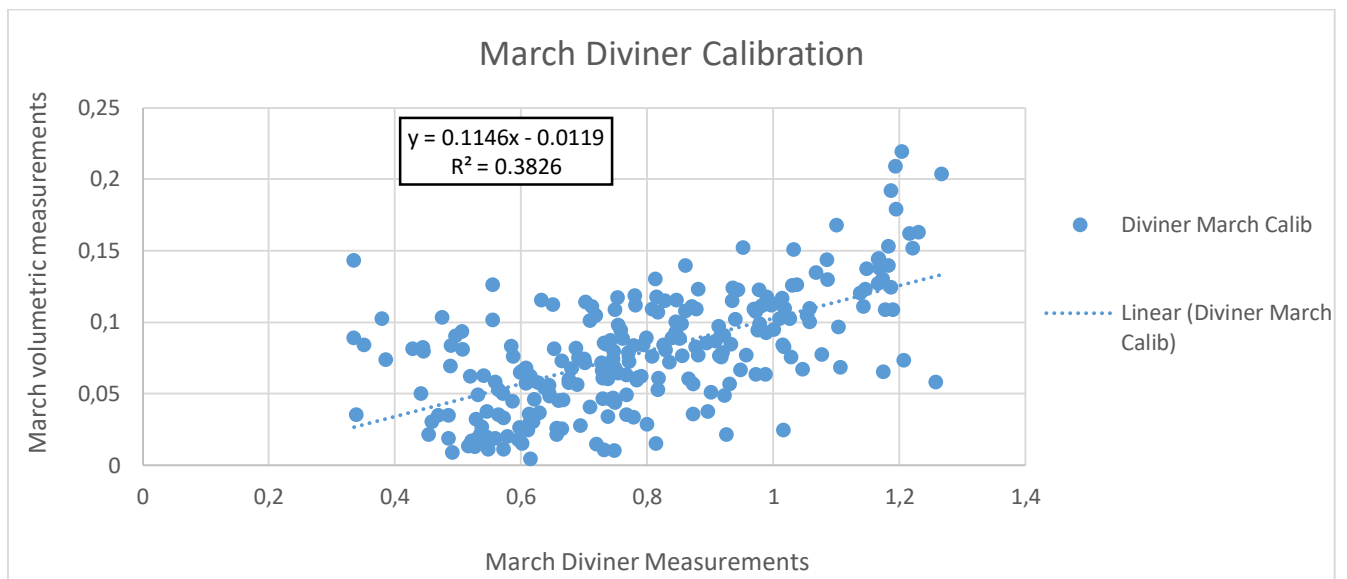


Figure 32: Scatterplot of the March volumetric measurements vs the March Diviner raw measurements to give a linear trend line. This equation was used to calculate the calibrated volumetric Diviner measurements for the month of March.

Table 39: March calibrated volumetric measurements for the Diviner, using the calculated equation.

March - Diviner Calibrated Volumetric Measurements								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
1.1	0.05010	0.05789						
2.2	0.04864	0.06943	0.09957	0.10924	0.13323			
2.3	0.03230	0.04626	0.04491	0.07041	0.12447			
2.4	0.06844	0.07321						
2.5	0.05776	0.06208						
2.6	0.05712	0.07789						
3.1	0.05674	0.08061	0.09990	0.10154	0.10638			
3.2	0.07502	0.09493	0.10132	0.10924				
3.3	0.07729	0.09370	0.10023	0.10477				
3.4	0.07199	0.07321	0.07812					
3.5	0.06196	0.05930						
3.6	0.06683							
3.7	0.06284	0.06943						
4.1	0.03868	0.05827	0.05993	0.06559	0.08815	0.08377		
4.2	0.06196	0.05853	0.07175	0.07765	0.08504		0.07441	0.12188
4.3	0.04759	0.06559	0.07150	0.06733	0.08423	0.09292		
4.4	0.02693	0.05363	0.07598					
4.5	0.02835	0.03909	0.02648	0.02648	0.05506	0.08119		
4.6	0.07907	0.08493	0.09913					
4.7	0.03717	0.04397	0.04411	0.05167	0.05167			
4.8								
4.9								
5.1	0.07308	0.06372	0.09055	0.09946	0.10262	0.10055	0.09582	0.11249
5.2	0.06447	0.07260	0.08178	0.08861	0.09924	0.09626	0.10616	0.10702

March - Diviner Calibrated Volumetric Measurements (continued)								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
5.3	0.05827	0.05063	0.05220	0.05532	0.06422			
5.4	0.06856	0.10012	0.12407	0.12358				
5.5	0.05776	0.07393	0.07369					
5.6	0.06967	0.08493						
5.7	0.04182	0.05827	0.07163					
5.8	0.03160	0.03895						
5.9	0.05545							
6.1	0.06832	0.08907	0.09213	0.10563	0.10381	0.09527	0.08295	0.11040
6.2	0.04970	0.06708	0.07453	0.07966	0.08562	0.08597	0.07393	
6.3	0.05350	0.07645	0.08272	0.09280	0.08666	0.11906		
6.4	0.06259	0.08167	0.10229					
6.5	0.04904	0.07223	0.08666	0.09715				
6.6	0.04249	0.04612						
6.7	0.07357	0.08307						
6.8	0.06057	0.07308	0.08143	0.12298	0.12198			
6.9	0.06107	0.07260	0.07872	0.07634	0.10273			
7.1	0.06334	0.07393	0.08609	0.08873	0.08907	0.09538	0.12258	
7.2	0.04004	0.04944	0.08735	0.08793	0.11259			
7.3	0.05661	0.08167	0.11936	0.12497	0.12909	0.12487		
7.4	0.04059	0.07453	0.08061					
7.5	0.10882	0.11845	0.12358	0.12743				
7.6	0.05272	0.11456	0.11967	0.12605				
7.7	0.05815	0.07598						
8.1	0.05363	0.07199	0.07978	0.09077	0.09471	0.09134	0.09348	0.10445
8.2	0.04838	0.06334	0.07729	0.07598	0.11145	0.13218		
8.3	0.04878	0.06019	0.09325	0.10424	0.11415	0.12178		
8.4	0.05272	0.07357	0.09782	0.12178	0.12407	0.12802		
8.5	0.04371	0.06596	0.07526	0.07753				
8.6	0.05635	0.05904	0.07175	0.09382	0.11487			
8.7	0.05220							
9.1	0.05063	0.05036	0.05441	0.06422	0.06758			
9.2	0.04732	0.05089	0.05853	0.05699	0.07381	0.09415	0.10456	
9.3	0.04371							
9.4	0.04785	0.07053	0.08815	0.09671	0.10797	0.12268	0.12645	
9.5	0.04438	0.08131	0.10121	0.10467	0.10595			

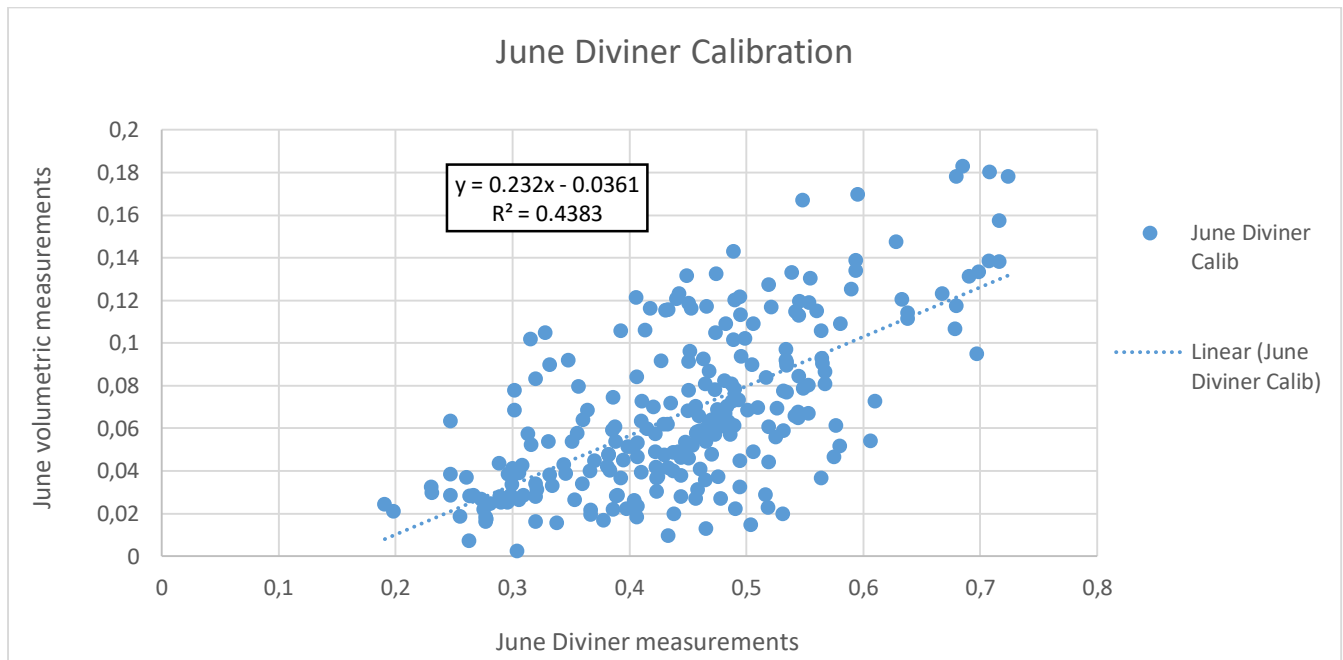


Figure 33: Scatterplot of the June volumetric measurements vs the June Diviner raw measurements to give a linear trend line. This equation was used to calculate the calibrated volumetric Diviner measurements for the month of June.

Table 40: June calibrated volumetric measurements for the Diviner, using the calculated equation.

June Diviner Calibrated Volumetric Measurements								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
1.1	0.04630	0.05329						
2.2	0.07076	0.09017	0.08433	0.09109	0.10957			
2.3	0.05278	0.06426	0.07364	0.08773	0.06606	0.13011	0.12820	0.13186
2.4	0.05261	0.06785						
2.5	0.04145	0.06541						
2.6	0.04972	0.06834						
3.1	0.04904	0.07396	0.08711	0.09726	0.09771			
3.2	0.03706	0.06344	0.07603	0.09502				
3.3	0.06393	0.07966	0.09381	0.12561				
3.4	0.04005	0.05227	0.06914					
3.5	0.03812	0.05631	0.06995					
3.6	0.05497							
3.7	0.07300	0.07730						
4.1	0.02121	0.05815	0.06979	0.09471	0.10450			
4.2	0.02904	0.06557	0.07476	0.07666	0.08727	0.08972	0.07856	0.11187
4.3	0.05981	0.05396	0.07412	0.07714	0.09487			
4.4	0.05159	0.08076	0.06687					
4.5	0.03388	0.04057	0.05345	0.06850	0.07603	0.07587		
4.6	0.04664	0.07492	0.09032					
4.7	0.03812	0.05832	0.07044	0.07840	0.09124			
4.8	0.03084	0.04371	0.06687					
4.9	0.04887							

June Diviner Calibrated Volumetric Measurements (continued)								
Profile	Depth (cm)							
	20	40	60	80	100	120	140	160
5.1	0.02832	0.04232	0.07777	0.08418	0.08372	0.08727	0.08573	0.08604
5.2	0.00812	0.04092	0.07012	0.07887	0.08107	0.09048	0.09260	0.10068
5.3	0.02121	0.05429	0.06541	0.07188	0.07364			
5.4	0.05798	0.06442	0.07761	0.10156				
5.5	0.04750	0.07172	0.08122					
5.6	0.04092	0.08433						
5.7	0.02487	0.07188	0.06442					
5.8	0.04836	0.06655						
5.9	0.05547							
6.1	0.03352	0.05497	0.06442	0.07746	0.07761	0.08387	0.06850	0.08895
6.2	0.03120	0.05765	0.05832	0.07172	0.07188	0.07571	0.06295	
6.3	0.02814	0.06229	0.07092	0.06866	0.08788	0.08788		
6.4	0.03724	0.04457	0.06899					
6.5	0.03830	0.05915	0.07380	0.06801				
6.6	0.04526	0.05379						
6.7	0.07252	0.09032						
6.8	0.03388	0.09546	0.11072	0.12602	0.13011			
6.9	0.06014	0.08956	0.08773	0.11187	0.12160			
7.1	0.03334	0.05615	0.07027	0.07300	0.07698	0.07205	0.09230	
7.2	0.02121	0.02778	0.05898	0.07140	0.06080			
7.3	0.03316	0.07540	0.08788	0.09471	0.10156	0.12160	0.12284	
7.4	0.02505	0.05345	0.05832	0.07428				
7.5	0.05815	0.08013	0.08480	0.10201				
7.6	0.03565	0.06361	0.09017	0.09860				
7.7	0.03476	0.05261						
8.1	0.03120	0.04904	0.05413	0.02433	0.02814	0.06492	0.07076	0.07555
8.2	0.03263	0.04578	0.06687	0.06639	0.09845	0.10537		
8.3	0.02305	0.06213	0.08122	0.07856	0.07300	0.09546		
8.4	0.03102	0.05898	0.09215		0.12132	0.12806		
8.5	0.03245	0.06850	0.07635	0.06979				
8.6	0.02578	0.03547	0.03654	0.06850	0.07871			
8.7	0.04405							
9.1	0.00983	0.04733	0.06196	0.06687	0.06834			
9.2	0.01733	0.01752	0.02724	0.06213	0.06180	0.06180	0.06147	
9.3	0.03441							
9.4	0.03476	0.05748	0.07252	0.09215	0.07730	0.11881	0.12409	
9.5	0.03812	0.03812	0.07856	0.08433	0.08216			

8.6 APPENDIX 6: SURFER MAPS AT THE MAXIMUM POSSIBLE DEPTHS FOR VOLUMETRIC-, NEUTRON PROBE- AND DIVINER DATASETS

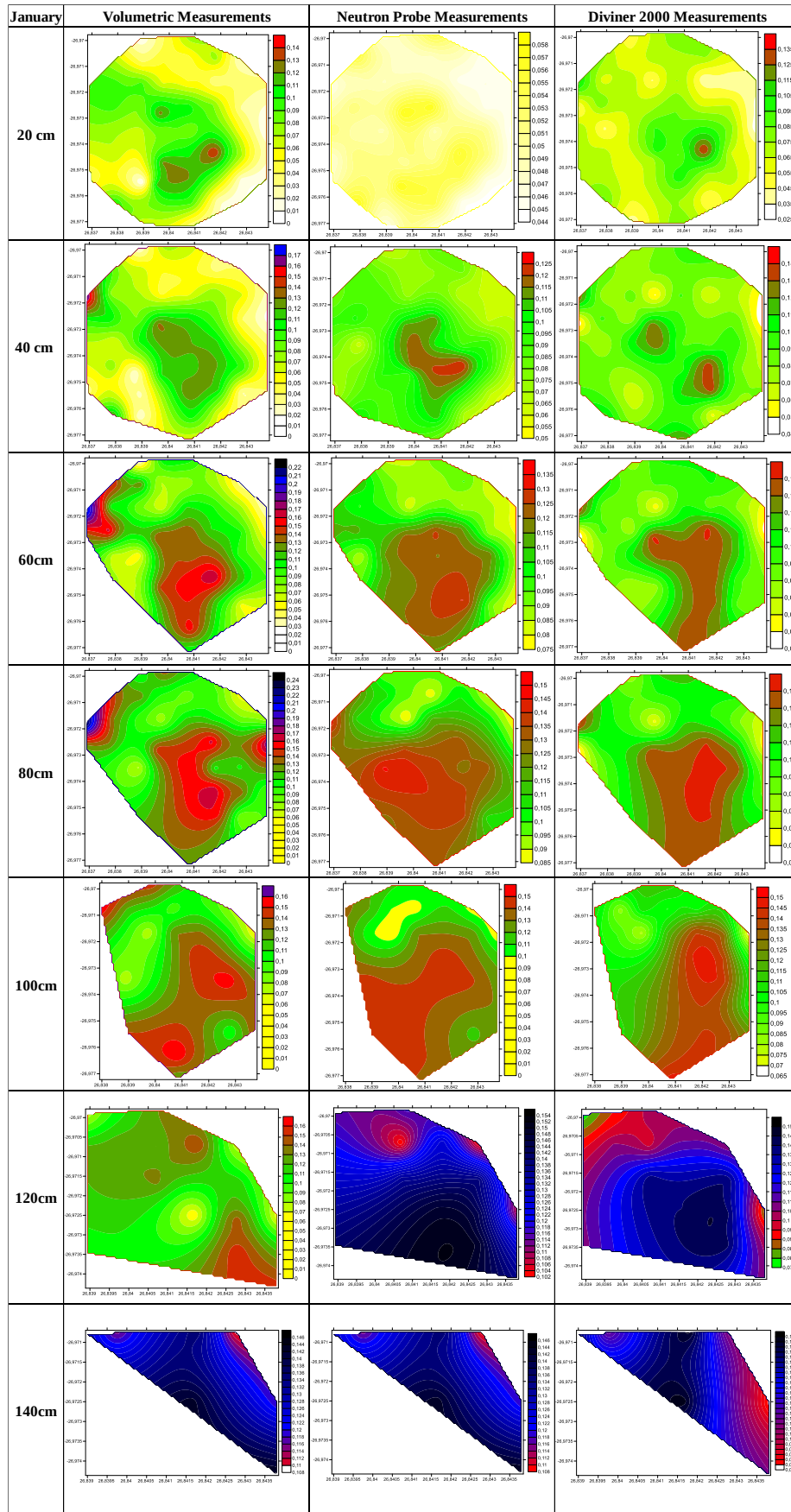


Figure 34: January Surfer maps of all the possible depths (up to 140 cm) with sufficient data, including volumetric, Neutron probe and Diviner datasets.

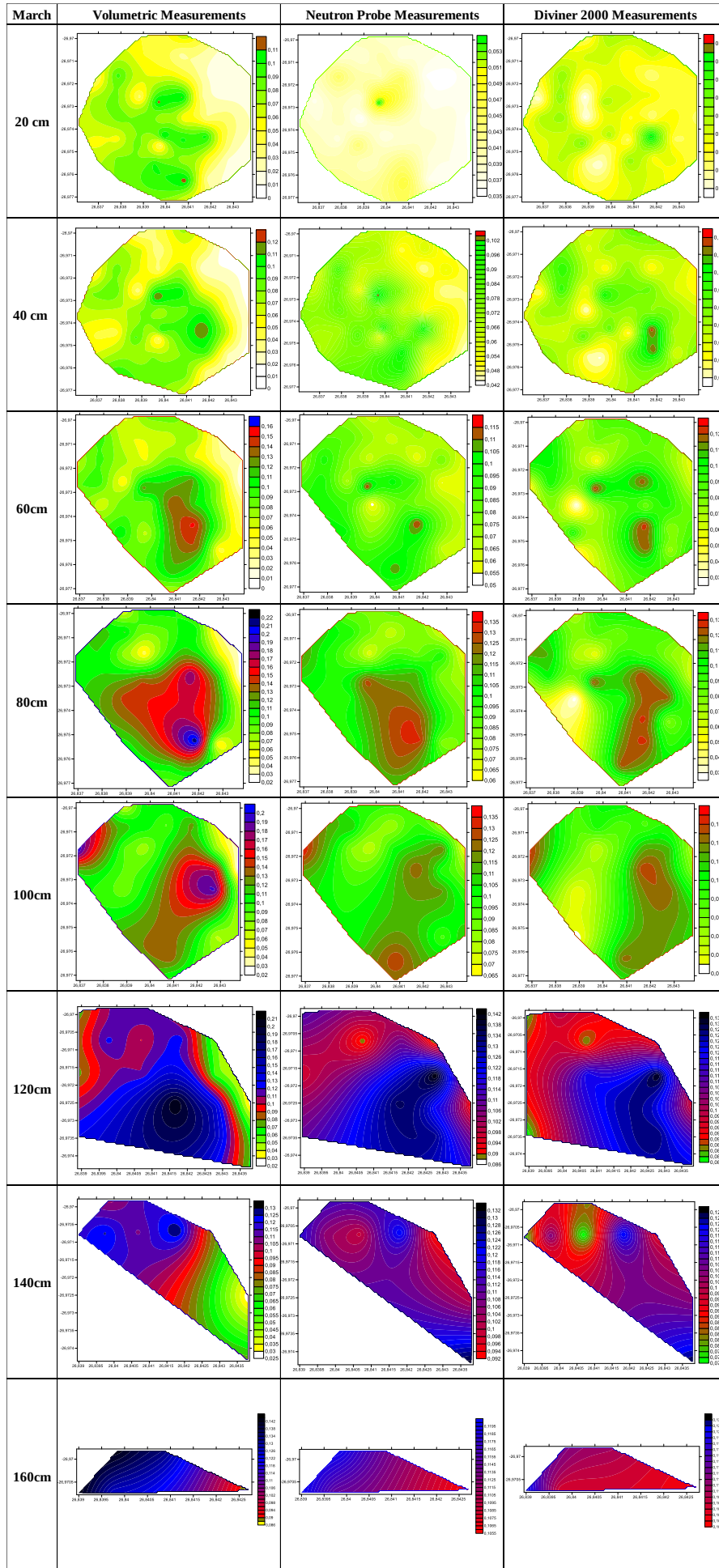


Figure 35: March Surf maps of all the possible depths (up to 160 cm) with sufficient data, including volumetric, Neutron probe and Diviner datasets.

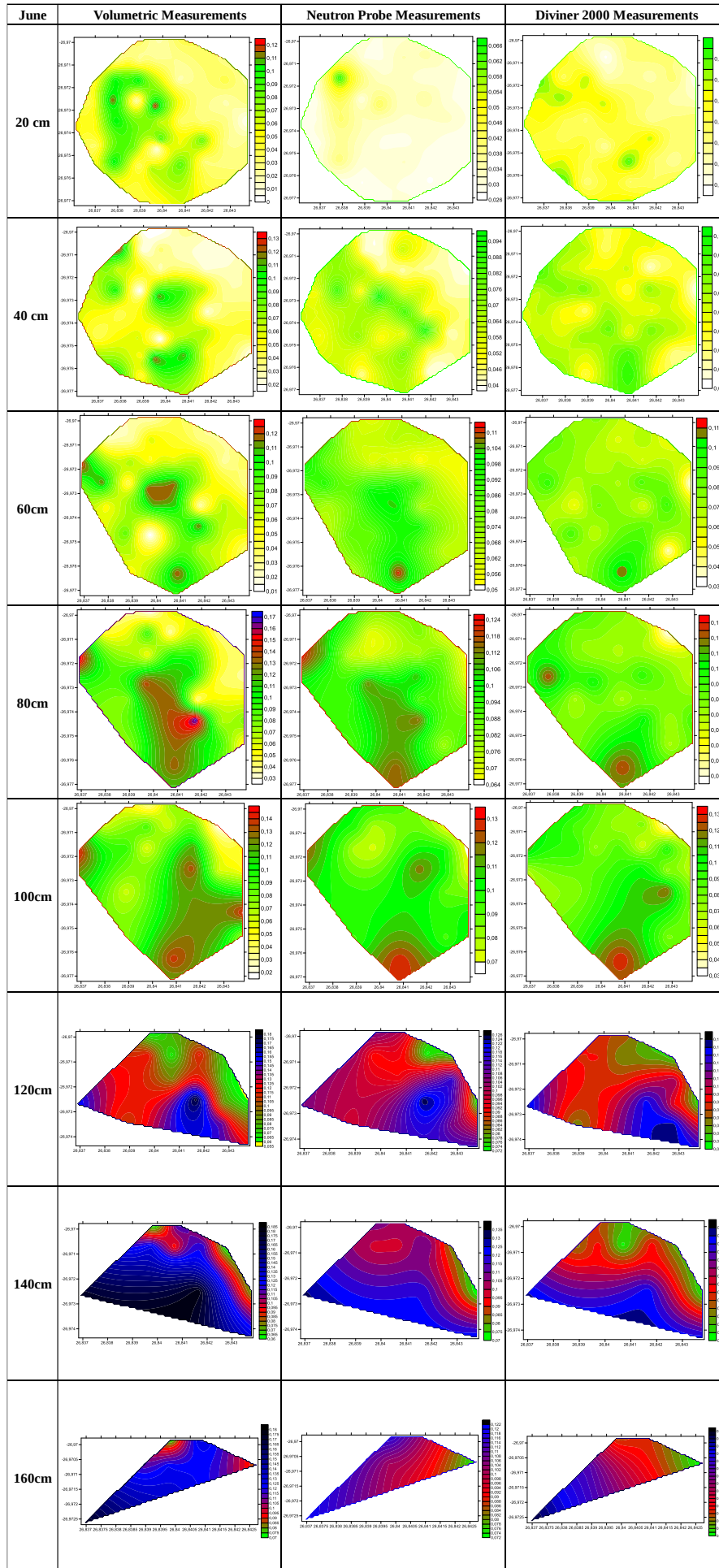


Figure 36: June Surfer maps of all the possible depths (up to 160 cm) with sufficient data, including volumetric, Neutron probe and Diviner datasets.

8.7 APPENDIX 7: SEMI-VARIOGRAMS OF ALL SURFER MAPS DISCUSSED

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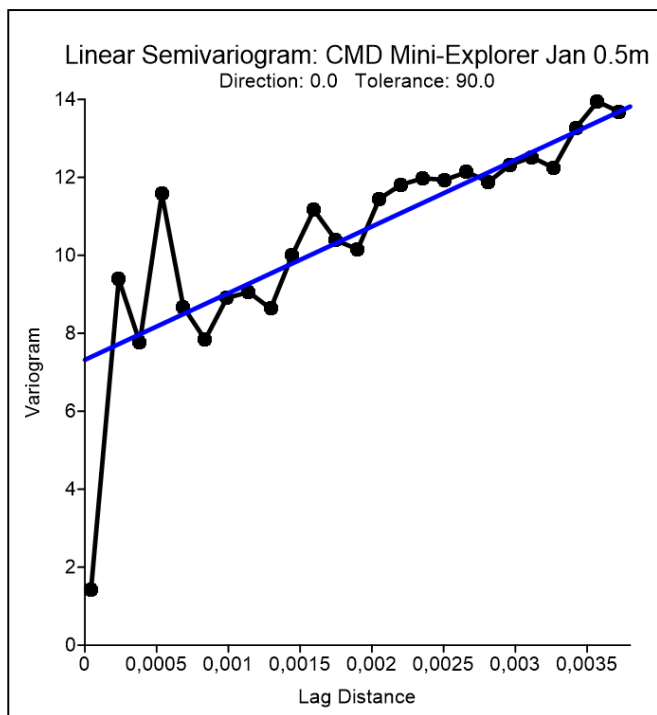


Figure 37: Linear Semi-variogram: CMD Mini-Explorer January 0.5 m.

Variogram Grid Report: CMD Mini-Explorer January 0.5 m

Variogram Grid

Maximum Lag Distance: 0.0038
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 50836

Original Data: 50836
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	-29.95
25%-tile:	26.84	-26.97	-1.8
Median:	26.84	-26.97	-0.07
75%-tile:	26.84	-26.97	2.08
Maximum:	26.84	-26.97	31.19
Midrange:	26.84	-26.97	0.62
Range:	0.009	0.008	61.14
Interquartile Range:	0.004	0.003	3.88
Median Abs. Deviation:	0.002	0.001	1.93
Mean:	26.84	-26.97	0.62
Trim Mean (10%):	26.84	-26.97	0.31
Standard Deviation:	0.002	0.002	3.44
Variance:	5.84E-006	3.38E-006	11.83
Coef. of Skewness:			1.8

Planar Regression: $Z = AX + BY + C$

Fitted Parameters

	A	B	C
Parameter Value:	114.532	-7.002	-3262.17
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-14282.9	-7141.45	-589.5
Residual:	50833	615811.93	12.11	
Total:	50835	601529.04		

Coefficient of Multiple Determination (R^2): -0.02

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	3.0E-007	0.02
Median:	1.14E-005	0.14
75%-tile:	1.97E-005	0.41
Maximum:	3.91E-005	27.49
Midrange:	1.95E-005	13.75
Range:	3.91E-005	27.49
Interquartile Range:	1.93E-005	0.39
Median Abs. Deviation:	9.19E-006	0.13
Mean:	1.16E-005	0.36
Trim Mean (10%):	1.131E-005	0.26
Standard Deviation:	9.4E-006	0.73
Variance:	8.83E-011	0.54
Coef. of Variation:	0.81	2.02
Coef. of Skewness:	0.18	9.58
Root Mean Square:	1.49E-005	0.82
Mean Square:	2.23E-010	0.67

Complete Spatial Randomness

Lambda: 779862417.09
Clark and Evans: 0.65
Skellam: 55578.69

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

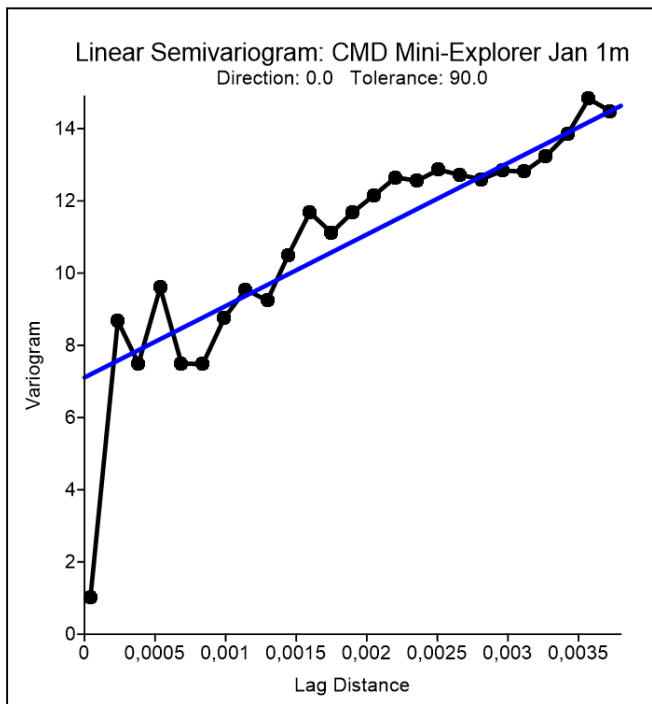


Figure 38: Linear Semi-variogram: CMD Mini-Explorer January 1 m.

Variogram Grid Report: CMD Mini-Explorer January 1 m

Variogram Grid

Maximum Lag Distance: 0.0038
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 50836

Original Data: 50836
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	-3.85
25%-tile:	26.84	-26.97	13.85
Median:	26.84	-26.97	15.51
75%-tile:	26.84	-26.97	18.66
Maximum:	26.84	-26.97	41.47
Midrange:	26.84	-26.97	18.81
Range:	0.009	0.008	45.32
Interquartile Range:	0.004	0.003	4.81
Median Abs. Deviation:	0.002	0.001	2.24
Mean:	26.84	-26.97	16.34
Trim Mean (10%):	26.84	-26.97	16.11
Standard Deviation:	0.002	0.002	3.68
Variance:	5.845E-006	3.38E-006	13.56
Coef. of Skewness:			1.08

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	145.77	-75.23	-5925.21
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-27133.27	-13566.63	-962.31
Residual:	50833	716640.59	14.1	
Total:	50835	689507.32		

Coefficient of Multiple Determination (R^2): -0.04

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	3.0E-007	0.04
Median:	1.14E-005	0.18
75%-tile:	1.97E-005	0.45
Maximum:	3.9E-005	17.41
Midrange:	1.95E-005	8.71
Range:	3.91E-005	17.41
Interquartile Range:	1.94E-005	0.41
Median Abs. Deviation:	9.19E-006	0.16
Mean:	1.16E-005	0.34
Trim Mean (10%):	1.13E-005	0.27
Standard Deviation:	9.4E-006	0.52
Variance:	8.83E-011	0.27
Coef. of Variation:	0.81	1.54
Coef. of Skewness:	0.18	6.99
Root Mean Square:	1.49E-005	0.62
Mean Square:	2.238E-010	0.38

Complete Spatial Randomness

Lambda: 779862417.09
Clark and Evans: 0.65
Skellam: 55578.69

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

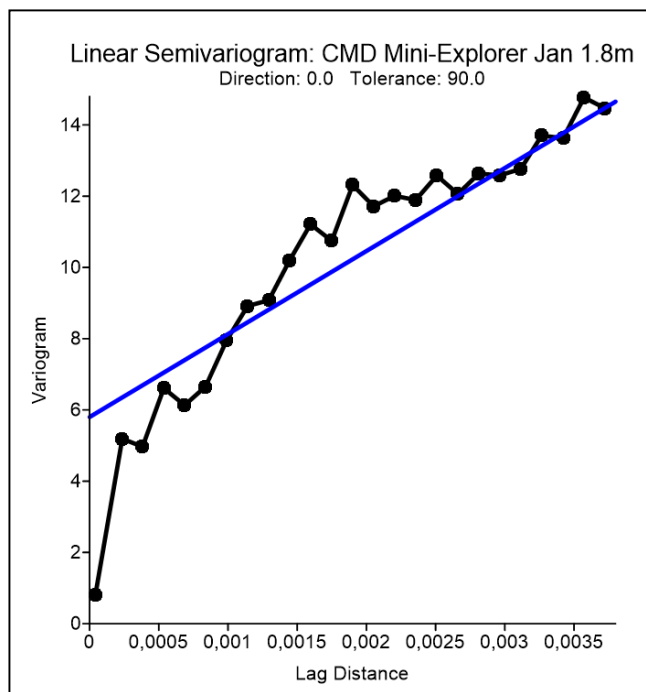


Figure 39: Linear Semi-variogram: CMD Mini-Explorer January 1.8 m.

Variogram Grid Report: CMD Mini-Explorer January 1.8 m

Variogram Grid

Maximum Lag Distance: 0.0038
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 50836

Original Data: 50836
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	4.48
25%-tile:	26.84	-26.97	10.42
Median:	26.84	-26.97	12.11
75%-tile:	26.84	-26.97	14.96
Maximum:	26.84	-26.97	36.93
Midrange:	26.84	-26.97	20.71
Range:	0.009	0.008	32.45
Interquartile Range:	0.004	0.003	4.54
Median Abs. Deviation:	0.002	0.001	2.17
Mean:	26.84	-26.97	12.88
Trim Mean (10%):	26.84	-26.97	12.69
Standard Deviation:	0.002	0.002	3.91
Variance:	5.85E-006	3.38E-006	15.27
Coef. of Variation:			0.3
Coef. of Skewness:			0.97

Planar Regression: $Z = AX + BY + C$

Fitted Parameters

	A	B	C
Parameter Value:	208.24	-140.68	-9370.85
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-61043.87	-30521.94	-1853.5
Residual:	50833	837063.51	16.47	
Total:	50835	776019.64		

Coefficient of Multiple Determination (R^2): -0.08

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	3.0E-007	0.07
Median:	1.14E-005	0.27
75%-tile:	1.97E-005	0.62
Maximum:	3.91E-005	11.51
Midrange:	1.95E-005	5.755
Range:	3.91E-005	11.51
Interquartile Range:	1.94E-005	0.55
Median Abs. Deviation:	9.19E-006	0.24
Mean:	1.16E-005	0.42
Trim Mean (10%):	1.13E-005	0.37
Standard Deviation:	9.4E-006	0.49
Variance:	8.83E-011	0.24
Coef. of Variation:	0.81	1.16
Coef. of Skewness:	0.18	2.99
Root Mean Square:	1.49E-005	0.65
Mean Square:	2.23E-010	0.42

Complete Spatial Randomness

Lambda: 779862417.09
Clark and Evans: 0.65
Skellam: 55578.693

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

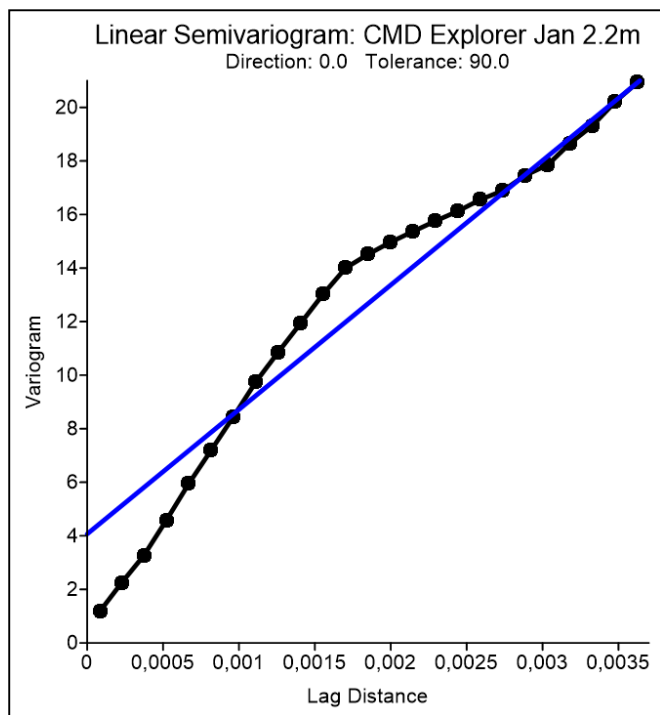


Figure 40: Linear Semi-variogram: CMD Explorer January 2.2 m.

Variogram Grid Report: CMD Explorer January 2.2 m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 27418

Original Data: 27418
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	1.87
25%-tile:	26.84	-26.97	8.47
Median:	26.84	-26.97	10.6
75%-tile:	26.84	-26.97	13.21
Maximum:	26.84	-26.97	36.75
Midrange:	26.84	-26.97	19.31
Range:	0.008	0.008	34.88
Interquartile Range:	0.004	0.003	4.74
Median Abs. Deviation:	0.002	0.001	2.34
Mean:	26.84	-26.97	11.54
Trim Mean (10%):	26.84	-26.97	11.17
Standard Deviation:	0.002	0.001	4.87
Variance:	4.78E-006	3.31E-006	23.71
Coef. of Variation:			0.42
Coef. of Skewness:			1.44

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	411.67	-513.86	-24898.09
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-124738.57	-62369.28	-2206.3
Residual:	27415	774996.46	28.27	
Total:	27417	650257.89		

Coefficient of Multiple Determination (R^2): -0.19

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	8.55E-006	0.13
Median:	1.01E-005	0.27
75%-tile:	1.17E-005	0.5
Maximum:	5.33E-005	7.94
Midrange:	2.67E-005	3.97
Range:	5.33E-005	7.94
Interquartile Range:	3.17E-006	0.37
Median Abs. Deviation:	1.58E-006	0.17
Mean:	9.89E-006	0.38
Trim Mean (10%):	1.008E-005	0.33
Standard Deviation:	2.6E-006	0.45
Variance:	6.81E-012	0.2
Coef. of Variation:	0.26	1.18
Coef. of Skewness:	-0.96	5.75
Root Mean Square:	1.02E-005	0.59
Mean Square:	1.05E-010	0.35

Complete Spatial Randomness

Lambda: 430362106.03
Clark and Evans: 0.41
Skellam: 7753.84

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

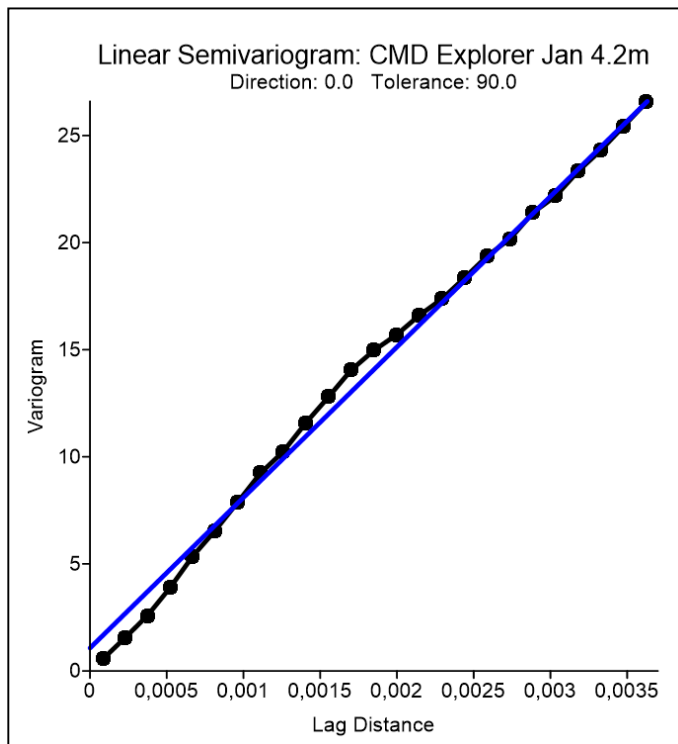


Figure 41: Linear Semi-variogram: CMD Explorer January 4.2 m.

Variogram Grid Report: CMD Explorer January 4.2 m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 27418
Original Data: 27418
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	5.46
25%-tile:	26.84	-26.97	11.09
Median:	26.84	-26.97	12.99
75%-tile:	26.84	-26.97	15.89
Maximum:	26.84	-26.97	42.3
Midrange:	26.84	-26.97	23.88
Range:	0.008	0.008	36.84
Interquartile Range:	0.004	0.003	4.8
Median Abs. Deviation:	0.002	0.001	2.17
Mean:	26.84	-26.97	14.48
Trim Mean (10%):	26.84	-26.97	13.95
Standard Deviation:	0.002	0.002	5.42
Variance:	4.78E-006	3.31E-006	29.35
Coef. of Variation:			0.37
Coef. of Skewness:			1.8

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	544.79	-527.98	-28849.25
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-173705.23	-86852.62	-2433.9
Residual:	27415	978278.99	35.68	
Total:	27417	804573.75		

Coefficient of Multiple Determination (R^2): -0.22

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	8.55E-006	0.09
Median:	1.01E-005	0.19
75%-tile:	1.17E-005	0.34
Maximum:	5.33E-005	8.3
Midrange:	2.67E-005	4.15
Range:	5.33E-005	8.3
Interquartile Range:	3.17E-006	0.25
Median Abs. Deviation:	1.58E-006	0.12
Mean:	9.89E-006	0.25
Trim Mean (10%):	1.01E-005	0.22
Standard Deviation:	2.61E-006	0.27
Variance:	6.81E-012	0.07
Coef. of Variation:	0.26	1.05
Coef. of Skewness:	-0.96	5.04
Root Mean Square:	1.02E-005	0.37
Mean Square:	1.05E-010	0.14

Complete Spatial Randomness

Lambda: 430362106.04
Clark and Evans: 0.41
Skellam: 7753.84

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

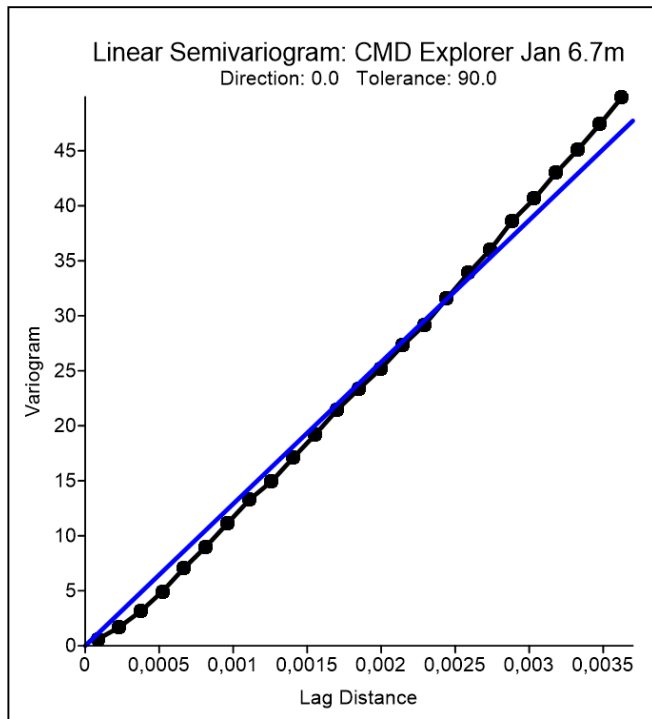


Figure 42: Linear Semi-variogram: CMD Explorer January 6.7 m.

Variogram Grid Report: CMD Explorer January 6.7 m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 27418
Original Data: 27418
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	5.46
25%-tile:	26.84	-26.97	10.93
Median:	26.84	-26.97	13.4
75%-tile:	26.84	-26.97	18.99
Maximum:	26.84	-26.97	48.97
Midrange:	26.84	-26.97	27.22
Range:	0.008	0.008	43.51
Interquartile Range:	0.004	0.003	8.06
Median Abs. Deviation:	0.008	0.001	2.95
Mean:	26.84	-26.97	16.1
Trim Mean (10%):	26.84	-26.97	15.38
Standard Deviation:	0.002	0.002	7.38
Variance:	4.788E-006	3.31E-006	54.42
Coef. of Variation:			0.46
Coef. of Skewness:			1.54

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	762.06	-843.99	-43203.02
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-380486.12	-190243.06	-2785.4
Residual:	27415	1872459.82	68.30	
Total:	27417	1491973.7		

Coefficient of Multiple Determination (R^2): -0.26

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	8.55E-006	0.07
Median:	1.01E-005	0.16
75%-tile:	1.17E-005	0.29
Maximum:	5.33E-005	11.84
Midrange:	2.67E-005	5.92
Range:	5.33E-005	11.84
Interquartile Range:	3.17E-006	0.22
Median Abs. Deviation:	1.58E-006	0.1
Mean:	9.89E-006	0.23
Trim Mean (10%):	1.01E-005	0.2
Standard Deviation:	2.61E-006	0.27
Variance:	6.81E-012	0.07
Coef. of Variation:	0.26	1.2
Coef. of Skewness:	-0.96	7.69
Root Mean Square:	1.02E-005	0.36
Mean Square:	1.059E-010	0.13

Complete Spatial Randomness

Lambda: 430362106.04
Clark and Evans: 0.41
Skellam: 7753.84

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

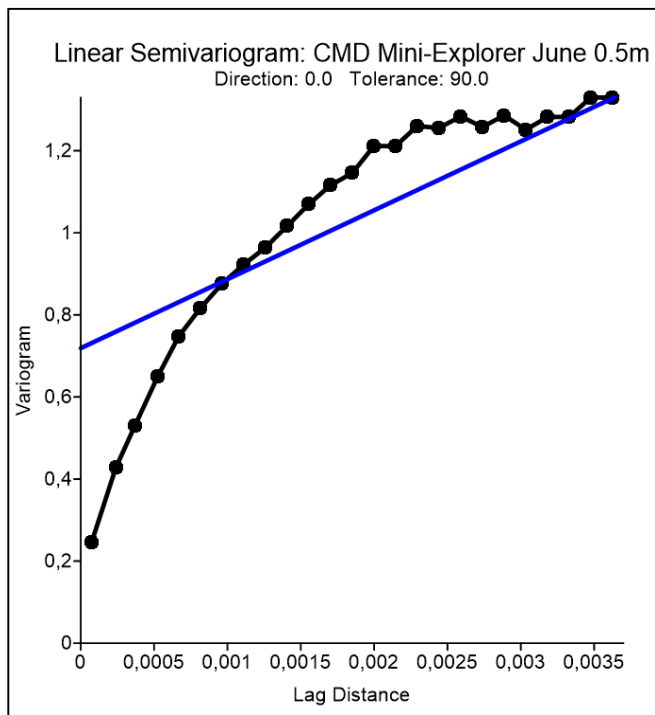


Figure 43: Linear Semi-variogram: CMD Mini-Explorer June 0.5 m.

Variogram Grid Report: CMD Mini-Explorer June 0.5 m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 50998

Original Data: 50998
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	0.05
25%-tile:	26.84	-26.98	3.46
Median:	26.84	-26.97	3.99
75%-tile:	26.84	-26.97	4.75
Maximum:	26.84	-26.96	19.2
Midrange:	26.84	-26.97	9.63
Range:	0.008	0.008	19.15
Interquartile Range:	0.003	0.003	1.29
Median Abs. Deviation:	0.001	0.002	0.61
Mean:	26.84	-26.97	4.23
Trim Mean (10%):	26.84	-26.97	4.13
Standard Deviation:	0.002	0.0024	1.19
Variance:	4.66E-006	3.87E-006	1.41
Coef. of Variation:			0.28
Coef. of Skewness:			1.96

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	166.32	-160.80	-8797.30
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-14086.87	-7043.44	-4167.2
Residual:	50995	86191.6	1.69	
Total:	50997	72104.73		

Coefficient of Multiple Determination (R^2): -0.2

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	0	0.1
Median:	0	0.22
75%-tile:	0	0.4
Maximum:	1.97E-005	10.07
Midrange:	9.85E-006	5.035
Range:	1.98E-005	10.07
Interquartile Range:	0	0.3
Median Abs. Deviation:	0	0.14
Mean:	2.71E-007	0.29
Trim Mean (10%):	0	0.26
Standard Deviation:	1.42E-006	0.33
Variance:	2.01E-012	0.11
Coef. of Variation:	5.24	1.13
Coef. of Skewness:	5.49	7.22
Root Mean Square:	1.44E-006	0.44
Mean Square:	2.08E-012	0.2

Complete Spatial Randomness

Lambda: 806272349.24
Clark and Evans: 0.015
Skellam: 538.59

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

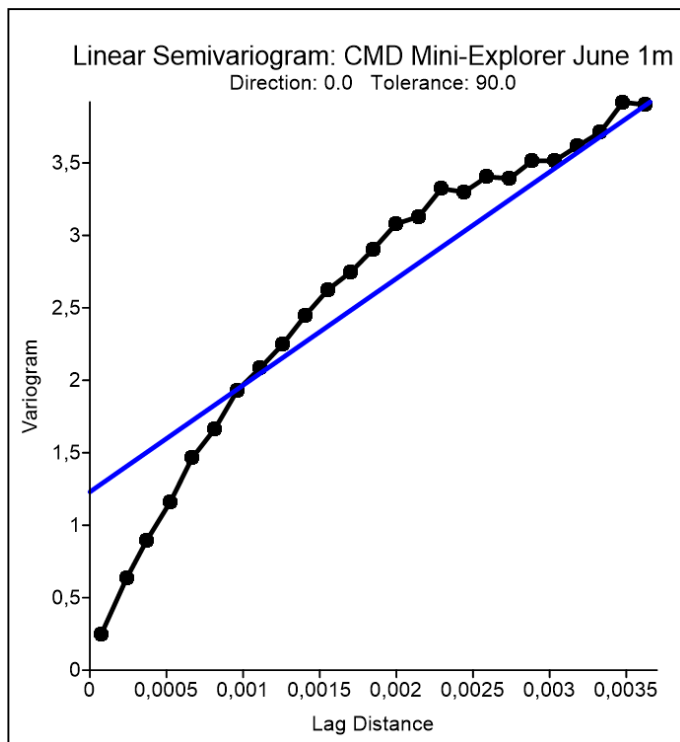


Figure 44: Linear Semi-variogram: CMD Mini-Explorer June 1 m.

Variogram Grid Report: CMD Mini-Explorer June 1 m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 50997
Original Data: 50997
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	1.32
25%-tile:	26.84	-26.98	4.89
Median:	26.84	-26.97	5.58
75%-tile:	26.84	-26.97	6.75
Maximum:	26.84	-26.97	21.07
Midrange:	26.84	-26.97	11.2
Range:	0.008	0.008	19.75
Interquartile Range:	0.003	0.003	1.86
Median Abs. Deviation:	0.002	0.002	0.84
Mean:	26.84	-26.97	6.13
Trim Mean (10%):	26.84	-26.97	5.9
Standard Deviation:	0.002	0.002	1.98
Variance:	4.66E-006	3.87E-006	3.91
Coef. of Variation:			0.32
Coef. of Skewness:			2.16

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-241.43	237.13	12882.22
Standard Deviation:	3.22	3.53	123.78

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	35124.76	17562.38	5455.1
Residual:	50994	164172.37	3.22	
Total:	50996	199297.13		

Coefficient of Multiple Determination (R^2): 0.18

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	0	0.05
Median:	0	0.12
75%-tile:	0	0.23
Maximum:	1.97E-005	4.85
Midrange:	9.85E-006	2.43
Range:	1.97E-005	4.85
Interquartile Range:	0	0.18
Median Abs. Deviation:	0	0.08
Mean:	2.7E-007	0.18
Trim Mean (10%):	0	0.15
Standard Deviation:	1.42E-006	0.2
Variance:	2.01E-012	0.038
Coef. of Variation:	5.25	1.11
Coef. of Skewness:	5.5	4.13
Root Mean Square:	1.44E-006	0.26
Mean Square:	2.08E-012	0.07

Complete Spatial Randomness

Lambda: 806256539.36
Clark and Evans: 0.015
Skellam: 537.29

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

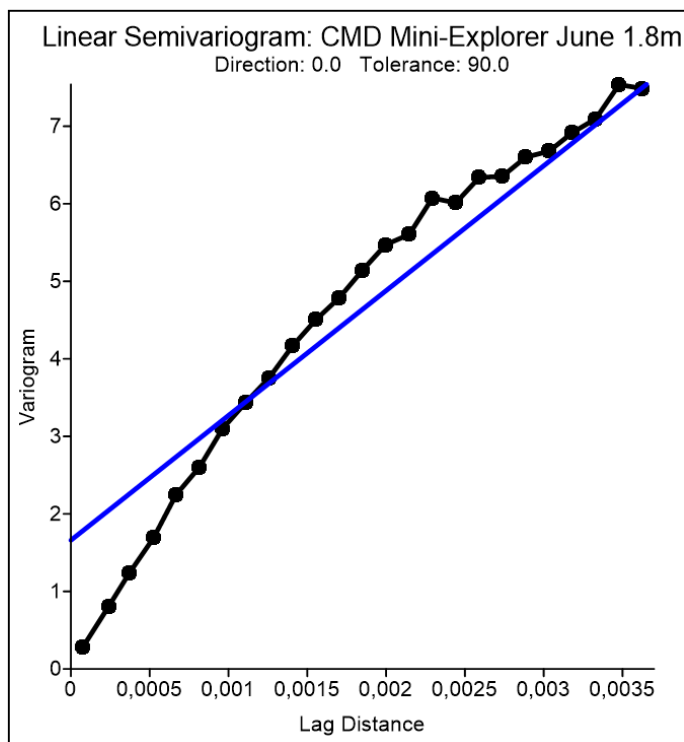


Figure 45: Linear Semi-variogram: CMD Mini-Explorer June 1.8 m.

Variogram Grid Report: CMD Mini-Explorer June 1.8m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 51012
Original Data: 51012
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.84	-26.98	3.3
25%-tile:	26.84	-26.98	5.76
Median:	26.84	-26.97	6.72
75%-tile:	26.84	-26.97	8.3
Maximum:	26.84	-26.97	26.19
Midrange:	26.84	-26.97	14.75
Range:	0.008	0.008	22.89
Interquartile Range:	0.003	0.003	2.54
Median Abs. Deviation:	0.002	0.002	1.125
Mean:	26.84	-26.97	7.51
Trim Mean (10%):	26.84	-26.97	7.2
Standard Deviation:	0.002	0.002	2.75
Variance:	4.66E-006	3.89E-006	7.54
Coef. of Variation:			0.37
Coef. of Skewness:			2.19

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	4130.59	-4368.96	-228704.10
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-989398.78	-494699.39	-18367
Residual:	51009	1373917.2	26.93	
Total:	51011	384518.42		

Coefficient of Multiple Determination (R^2): -2.57

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	0	0.05
Median:	0	0.1
75%-tile:	0	0.19
Maximum:	1.97E-005	3.32
Midrange:	9.845E-006	1.66
Range:	1.97E-005	3.32
Interquartile Range:	0	0.14
Median Abs. Deviation:	0	0.07
Mean:	2.7E-007	0.14
Trim Mean (10%):	0	0.13
Standard Deviation:	1.42E-006	0.14
Variance:	2.006E-012	0.02
Coef. of Variation:	5.251	1.003
Coef. of Skewness:	5.5	3.2
Root Mean Square:	1.44E-006	0.2
Mean Square:	2.08E-012	0.04

Complete Spatial Randomness

Lambda: 806493687.58798
Clark and Evans: 0.015319880715233
Skellam: 537.39239200606

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

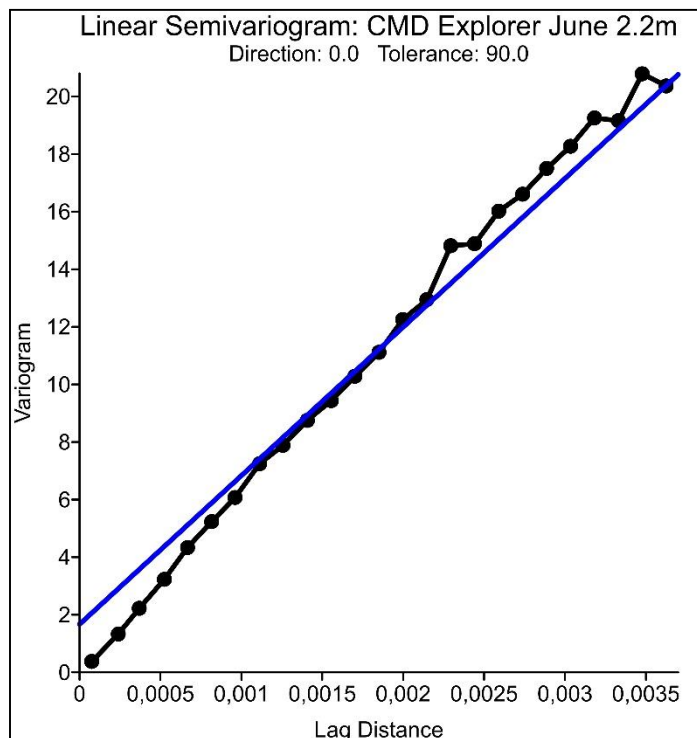


Figure 46: Linear Semi-variogram: CMD Explorer June 2.2 m.

Variogram Grid Report: CMD Explorer June 2.2m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 44243
Original Data: 44243
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.83	-26.97	3.04
25%-tile:	26.83	-26.97	8.33
Median:	26.84	-26.97	10.1
75%-tile:	26.84	-26.97	12.84
Maximum:	26.84	-26.96	35.89
Midrange:	26.84	-26.97	19.46
Range:	0.008	0.007	32.85
Interquartile Range:	0.003	0.003	4.51
Median Abs. Deviation:	0.001	0.001	2.02
Mean:	26.83	-26.97	11.34
Trim Mean (10%):	26.83	-26.97	10.91
Standard Deviation:	0.002	0.001	4.56
Variance:	4.58E-006	3.93E-006	20.84
Coef. of Variation:			0.40
Coef. of Skewness:			1.71

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-224.06	302.58	14187.06
Standard Deviation:	4.84	5.23	185.36

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	108032.14	54016.07	2934.8
Residual:	44240	814265.64	18.40	
Total:	44242	922297.79		

Coefficient of Multiple Determination (R^2): 0.12

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	0	0.07
Median:	0	0.16
75%-tile:	0	0.29
Maximum:	1.39E-005	11.55
Midrange:	6.96E-006	5.775
Range:	1.39E-005	11.55
Interquartile Range:	0	0.22
Median Abs. Deviation:	0	0.1
Mean:	9.64E-008	0.21
Trim Mean (10%):	0	0.19
Standard Deviation:	9.06E-007	0.22
Variance:	8.21E-013	0.05
Coef. of Variation:	9.39	1.06
Coef. of Skewness:	9.60	7.88
Root Mean Square:	9.11E-007	0.32
Mean Square:	8.30E-013	0.1

Complete Spatial Randomness

Lambda: 701760329.853
Clark and Evans: 0.005
Skellam: 162.07

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

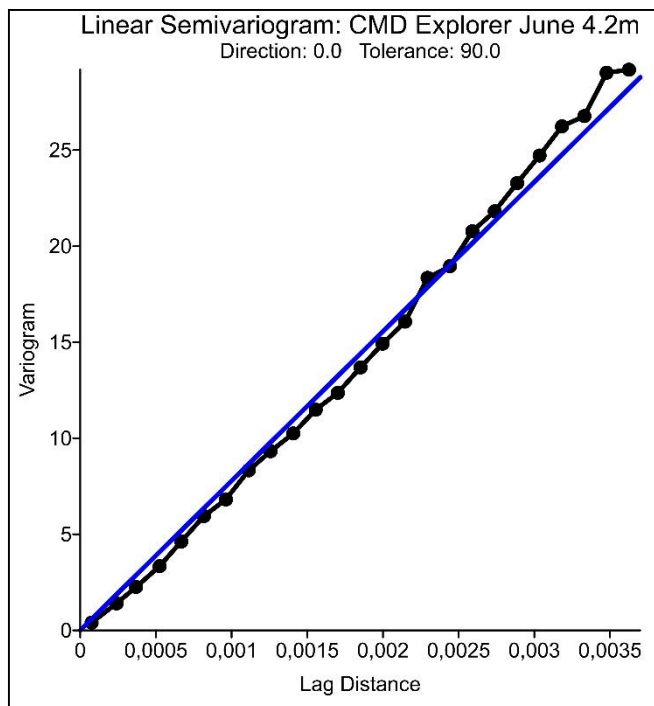


Figure 47: Linear Semi-variogram: CMD Explorer June 4.2 m.

Variogram Grid Report: CMD Explorer June 4.2m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 44243
Original Data: 44243
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.83	-26.97	1.47
25%-tile:	26.83	-26.97	8.64
Median:	26.84	-26.97	10.42
75%-tile:	26.84	-26.97	14.86
Maximum:	26.84	-26.96	39.92
Midrange:	26.84	-26.97	20.69
Range:	0.008	0.008	38.45
Interquartile Range:	0.003	0.003	6.22
Median Abs. Deviation:	0.002	0.002	2.21
Mean:	26.84	-26.97	12.54
Trim Mean (10%):	26.84	-26.97	11.95
Standard Deviation:	0.002	0.002	5.61
Variance:	4.58E-006	3.94E-006	31.54
Coef. of Variation:			0.45
Coef. of Skewness:			1.66

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-369.33	384.35	20292.88
Standard Deviation:	5.82	6.28	222.63

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	220962.49	110481.24	4161.5
Residual:	44240	1174488.73	26.55	
Total:	44242	1395451.22		

Coefficient of Multiple Determination (R^2): 0.16

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	0	0.06
Median:	0	0.14
75%-tile:	0	0.25
Maximum:	1.39E-005	10.59
Midrange:	6.96E-006	5.295
Range:	1.39E-005	10.59
Interquartile Range:	0	0.19
Median Abs. Deviation:	0	0.09
Mean:	9.65E-008	0.17
Trim Mean (10%):	0	0.16
Standard Deviation:	9.06E-007	0.20
Variance:	8.21E-013	0.04
Coef. of Variation:	9.4	1.09
Coef. of Skewness:	9.6	9.06
Root Mean Square:	9.11E-007	0.28
Mean Square:	8.30E-013	0.08

Complete Spatial Randomness

Lambda: 701760329.85
Clark and Evans: 0.005
Skellam: 162.07

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

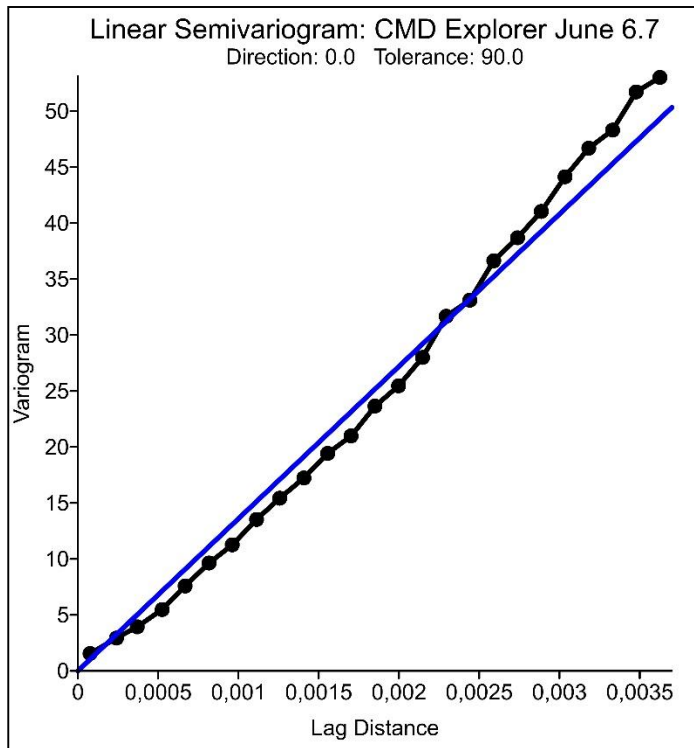


Figure 48: Linear Semi-variogram: CMD Explorer June 6.7 m.

Variogram Grid Report: CMD Explorer June 6.7m

Variogram Grid

Maximum Lag Distance: 0.0037
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 44243
Original Data: 44243
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	26.83	-26.98	2.18
25%-tile:	26.83	-26.98	9.6
Median:	26.84	-26.97	11.35
75%-tile:	26.84	-26.97	18.81
Maximum:	26.84	-26.96	207.53
Midrange:	26.84	-26.97	104.86
Range:	0.008	0.008	205.35
Interquartile Range:	0.003	0.003	9.21
Median Abs. Deviation:	0.002	0.002	2.53
Mean:	26.83	-26.97	14.89
Trim Mean (10%):	26.83	-26.97	14.14
Standard Deviation:	0.002	0.002	7.57
Variance:	4.58E-006	3.94E-006	57.27
Coef. of Variation:			0.51
Coef. of Skewness:			1.8

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-503.81	541.33	28138.9
Standard Deviation:	7.8	8.42	298.34

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	424477.85	212238.93	4451.8
Residual:	44240	2109134.19	47.67	
Total:	44242	2533612.04		

Coefficient of Multiple Determination (R^2): 0.17

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0	0
25%-tile:	0	0.06
Median:	0	0.13
75%-tile:	0	0.23
Maximum:	1.39E-005	158.78
Midrange:	6.96E-006	79.39
Range:	1.39E-005	158.78
Interquartile Range:	0	0.17
Median Abs. Deviation:	0	0.08
Mean:	9.65E-008	0.19
Trim Mean (10%):	0	0.15
Standard Deviation:	9.06E-007	1.11
Variance:	8.21E-013	1.24
Coef. of Variation:	9.4	5.84
Coef. of Skewness:	9.6	132.24
Root Mean Square:	9.11E-007	1.13
Mean Square:	8.31E-013	1.27

Complete Spatial Randomness

Lambda: 701760329.85
Clark and Evans: 0.005
Skellam: 162.068

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

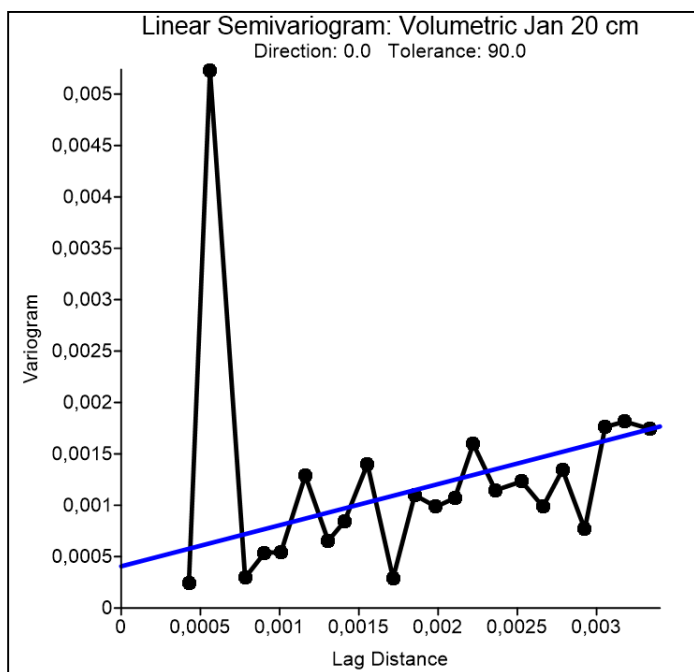


Figure 49: Linear Semi-variogram: Volumetric January 20 cm.

Variogram Grid Report: Volumetric January 20 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 55
Original Data: 55
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.008
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.07
75%-tile:	-26.98	26.84	0.08
Maximum:	-26.98	26.84	0.14
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.007	0.13
Interquartile Range:	0.004	0.003	0.05
Median Abs. Deviation:	0.002	0.002	0.03
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.846	0.06
Standard Deviation:	0.002	0.0024	0.03
Variance:	4.063E-006	4.33E-006	0.001
Coef. of Variation:			0.54
Coef. of Skewness:			0.07

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.46	-2.94	66.47
Standard Deviation:	1.50	1.46	56.07

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.005	0.002	2.09
Residual:	52	0.056	0.001	
Total:	54	0.06		

Coefficient of Multiple Determination (R^2): 0.07

Nearest Neighbor Statistics

	Separation	Delta
Z		
Minimum:	0.0004	0.001
25%-tile:	0.00084	0.01
Median:	0.00094	0.02
75%-tile:	0.0009	0.04
Maximum:	0.001	0.1
Midrange:	0.0007	0.05
Range:	0.0006	0.1
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	4.01E-005	0.01
Mean:	0.0009	0.03
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.02
Variance:	1.43E-008	
	0.0005	
Coef. of Variation:	0.14	0.81
Coef. of Skewness:	-2.09	1.58
Root Mean Square:	0.0009	0.03
Mean Square:	7.42E-007	0.001

Complete Spatial Randomness

Lambda: 1053015.59
Clark and Evans: 1.75
Skellam: 270.1

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

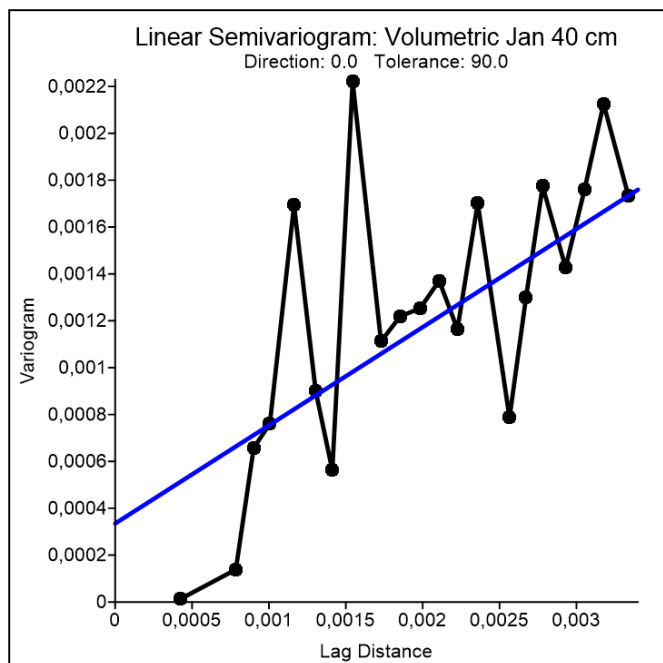


Figure 50: Linear Semi-variogram: Volumetric January 40 cm.

Variogram Grid Report: Volumetric January 40 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 51
Original Data: 51
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.014
25%-tile:	-26.97	26.84	0.047
Median:	-26.97	26.84	0.07
75%-tile:	-26.98	26.84	0.11
Maximum:	-26.98	26.84	0.18
Midrange:	-26.97	26.84	0.1
Range:	0.007	0.007	0.16
Interquartile Range:	0.003	0.003	0.06
Median Abs. Deviation:	0.002	0.002	0.03
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.07
Standard Deviation:	0.002	0.002	0.04
Variance:	3.8E-006	4.26E-006	0.001
Coef. of Variation:			0.5
Coef. of Skewness:			0.33

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-2.08	-3.58	40.16
Standard Deviation:	2.44	2.3	89.01

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.004	0.002	1.54
Residual:	48	0.07	0.0017	
Total:	50	0.07		

Coefficient of Multiple Determination (R^2): 0.06

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.003
25%-tile:	0.0008	0.009
Median:	0.0009	0.02
75%-tile:	0.0009	0.028
Maximum:	0.001	0.11
Midrange:	0.0007	0.05
Range:	0.0006	0.1
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	5.24E-005	0.01
Mean:	0.0009	0.03
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.022
Variance:	1.21E-008	0.0005
Coef. of Variation:	0.13	0.88
Coef. of Skewness:	-2.44	1.57
Root Mean Square:	0.0009	0.03
Mean Square:	7.635E-007	0.001

Complete Spatial Randomness

Lambda: 976432.64
Clark and Evans: 1.71
Skellam: 238.77

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

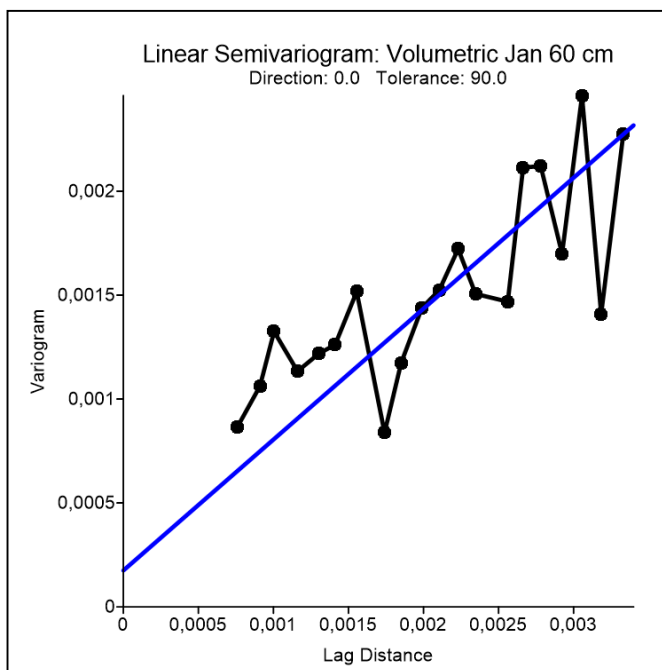


Figure 51: Linear Semi-variogram: Volumetric January 60 cm.

Variogram Grid Report: Volumetric January 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 42
Original Data: 42
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.02
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.1
75%-tile:	-26.97	26.84	0.13
Maximum:	-26.97	26.84	0.22
Midrange:	-26.97	26.84	0.12
Range:	0.007	0.007	0.2
Interquartile Range:	0.003	0.003	0.06
Median Abs. Deviation:	0.001	0.002	0.03
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.1
Standard Deviation:	0.002	0.0023	0.04
Variance:	3.44E-006	4.07E-006	0.002
Coef. of Variation:			0.42
Coef. of Skewness:			0.41

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	2.52	5.378	-76.36
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.008	-0.004	-1.85
Residual:	39	0.08	0.002	
Total:	41	0.07		

Coefficient of Multiple Determination (R^2): -0.1

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	0.001
25%-tile:	0.0008	0.01
Median:	0.0009	0.03
75%-tile:	0.0009	0.06
Maximum:	0.001	0.1
Midrange:	0.0009	0.05
Range:	0.0003	0.1
Interquartile Range:	8.96E-005	0.047
Median Abs. Deviation:	2.42E-005	0.02
Mean:	0.0009	0.04
Trim Mean (10%):	0.0009	0.03
Standard Deviation:	6.39E-005	0.03
Variance:	4.08E-009	0.0007
Coef. of Variation	0.07	0.75
Coef. of Skewness:	-1.02	0.52
Root Mean Square:	0.0009	0.04
Mean Square:	8.11E-007	0.002

Complete Spatial Randomness

Lambda: 804120.99
Clark and Evans: 1.61
Skellam: 172.15

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

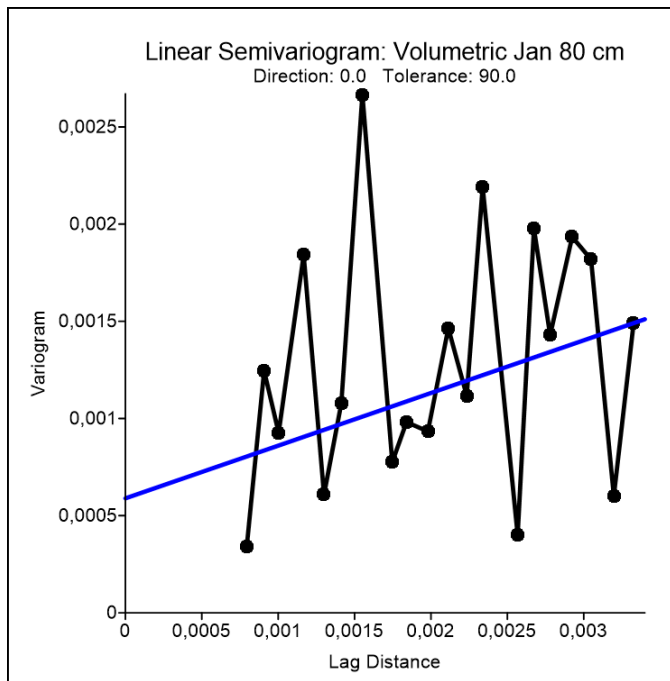


Figure 52: Linear Semi-variogram: Volumetric January 80 cm.

Variogram Grid Report: Volumetric January 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 36
Original Data: 36
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.05
25%-tile:	-26.97	26.84	0.09
Median:	-26.97	26.84	0.12
75%-tile:	-26.97	26.84	0.13
Maximum:	-26.97	26.84	0.24
Midrange:	-26.97	26.84	0.148
Range:	0.007	0.007	0.19
Interquartile Range:	0.003	0.004	0.041
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.12
Trim Mean (10%):	-26.97	26.84	0.11
Standard Deviation:	0.002	0.002	0.04
Variance:	3.7E-006	4.15E-006	0.001
Coef. of Variation:			0.31
Coef. of Skewness:			0.89

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.08	-1.56	12.96
Standard Deviation:	1.75	1.65	54.85

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0007	0.51
Residual:	33	0.05	0.001	
Total:	35	0.05		

Coefficient of Multiple Determination (R^2): 0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.004
25%-tile:	0.0009	0.01
Median:	0.0009	0.03
75%-tile:	0.0009	0.06
Maximum:	0.002	0.12
Midrange:	0.001	0.06
Range:	0.001	0.12
Interquartile Range:	5.33E-005	0.05
Median Abs. Deviation:	2.65E-005	0.02
Mean:	0.001	0.04
Trim Mean (10%):	0.001	0.04
Standard Deviation:	0.0002	0.03
Variance:	3.6E-008	0.001
Coef. of Variation:	0.2	0.79
Coef. of Skewness:	4.68	0.94
Root Mean Square:	0.001	0.05
Mean Square:	9.21E-007	0.003

Complete Spatial Randomness

Lambda: 689246.57
Clark and Evans: 1.56
Skellam: 143.6

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

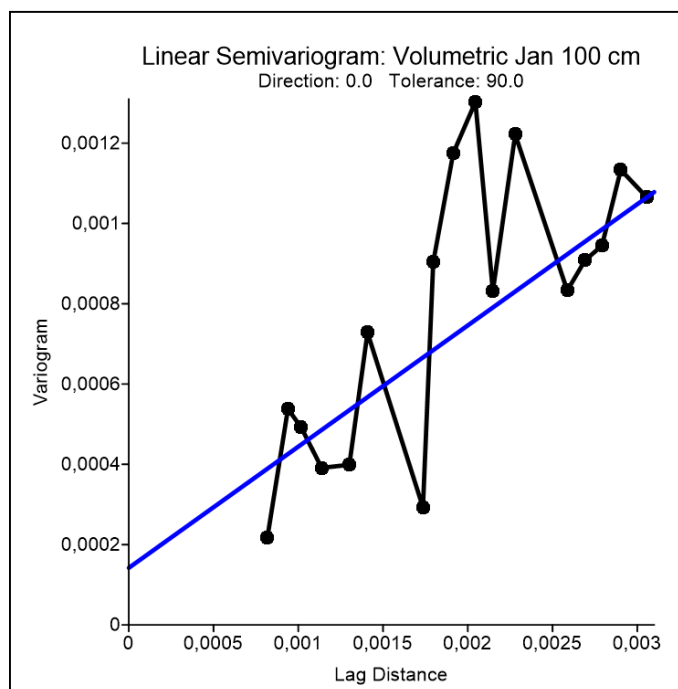


Figure 53: Linear Semi-variogram: Volumetric January 100 cm.

Variogram Grid Report: Volumetric January 100 cm

Variogram Grid

Maximum Lag Distance: 0.0031
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 24

Original Data: 24
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.055
25%-tile:	-26.97	26.84	0.1
Median:	-26.97	26.84	0.12
75%-tile:	-26.97	26.84	0.14
Maximum:	-26.97	26.84	0.16
Midrange:	-26.97	26.84	0.11
Range:	0.007	0.006	0.11
Interquartile Range:	0.004	0.003	0.041
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.12
Trim Mean (10%):	-26.97	26.84	0.12
Standard Deviation:	0.002	0.002	0.03
Variance:	4.58E-006	3.12E-006	0.0001
Coef. of Variation:			0.25
Coef. of Skewness:			-0.34

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	65.88	41.07	674.62
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.03	-0.01	-6.1
Residual:	21	0.05	0.002	
Total:	23	0.02		

Coefficient of Multiple Determination (R^2): -1.39

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.001
25%-tile:	0.0008	0.02
Median:	0.0009	0.03
75%-tile:	0.001	0.04
Maximum:	0.002	0.07
Midrange:	0.001	0.03
Range:	0.001	0.07
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	3.63E-005	0.01
Mean:	0.001	0.03
Trim Mean (10%):	0.0009	0.03
Standard Deviation:	0.0003	0.01
Variance:	8.2E-008	0.0002
Coef. of Variation:	0.29	0.49
Coef. of Skewness:	2.6	0.3
Root Mean Square:	0.001	0.03
Mean Square:	1.07E-006	0.001

Complete Spatial Randomness

Lambda: 547256.14
Clark and Evans: 1.47
Skellam: 88.48

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

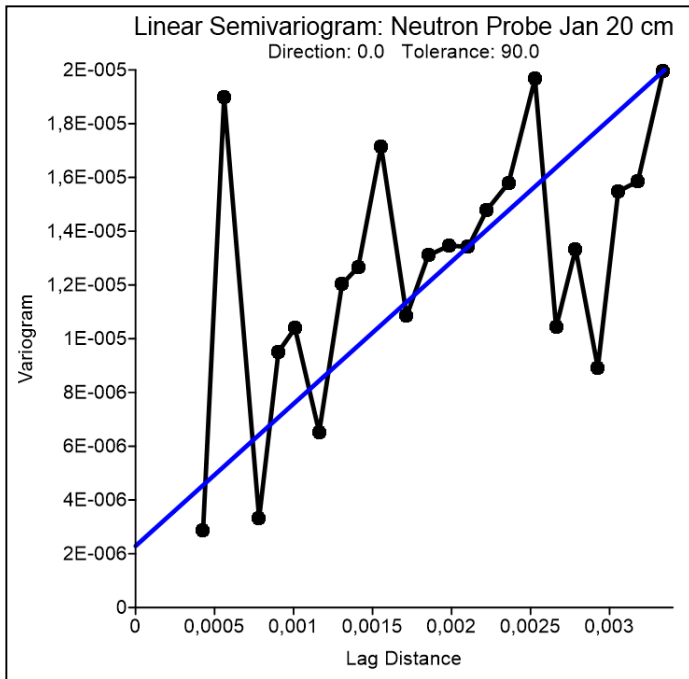


Figure 54: Linear Semi-variogram: Neutron probe January 20 cm.

Variogram Grid Report: Neutron probe January 20 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 55
Original Data: 55
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.05
Median:	-26.97	26.84	0.05
75%-tile:	-26.97	26.84	0.05
Maximum:	-26.97	26.84	0.06
Midrange:	-26.97	26.84	0.05
Range:	0.01	0.01	0.01
Interquartile Range:	0.004	0.003	0.01
Median Abs. Deviation:	0.002	0.002	0.002
Mean:	-26.97	26.84	0.05
Trim Mean (10%):	-26.97	26.84	0.05
Standard Deviation:	0.002	0.002	0.004
Variance:	4.06E-006	4.33E-006	1.46E-005
Coef. of Variation:			0.08
Coef. of Skewness:			0.57

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.1	-0.25	3.9
Standard Deviation:	0.17	0.16	6.29

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	3.93E-005	1.96E-005	1.36
Residual:	52	0.0007	1.44E-005	
Total:	54	0.0008		

Coefficient of Multiple Determination (R^2): 0.05

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0004
25%-tile:	0.0008	0.001
Median:	0.0009	0.003
75%-tile:	0.0009	0.005
Maximum:	0.001	0.009
Midrange:	0.0007	0.005
Range:	0.0006	0.008
Interquartile Range:	0.0001	0.004
Median Abs. Deviation:	4.012E-005	0.002
Mean:	0.0009	0.003
Trim Mean (10%):	0.0009	0.003112
Standard Deviation:	0.0001	0.003
Variance:	1.43E-008	6.57E-006
Coef. of Variation:	0.14	0.77
Coef. of Skewness:	-2.09	0.72
Root Mean Square:	0.0009	0.004
Mean Square:	7.42E-007	1.74E-005

Complete Spatial Randomness

Lambda: 1053015.59
Clark and Evans: 1.75
Skellam: 270.1

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

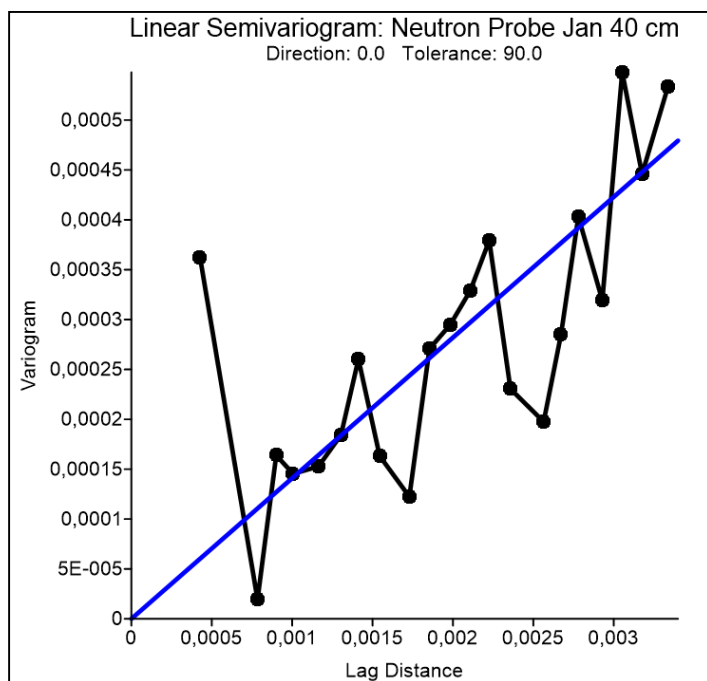


Figure 55: Linear Semi-variogram: Neutron probe January 40 cm.

Variogram Grid Report: Neutron probe January 40 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 51
Original Data: 51
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.05
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.1
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.09
Range:	0.007	0.007	0.07
Interquartile Range:	0.0037	0.0021	0.03
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.09
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.002	0.002	0.02
Variance:	3.8E-006	4.26E-006	0.0003
Coef. of Variation:			0.21
Coef. of Skewness:			0.40

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-2.06	-1.44	-16.74
Standard Deviation:	1.16	1.1	42.44

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0007	2.37
Residual:	48	0.02	0.0003	
Total:	50	0.02		

Coefficient of Multiple Determination (R^2): 0.09

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0004
25%-tile:	0.001	0.006
Median:	0.001	0.01
75%-tile:	0.001	0.02
Maximum:	0.001	0.04
Midrange:	0.001	0.02
Range:	0.001	0.04
Interquartile Range:	0.0001	0.01
Median Abs. Deviation:	5.24E-005	0.01
Mean:	0.001	0.01
Trim Mean (10%):	0.001	0.01
Standard Deviation:	0.0001	0.01
Variance:	1.21E-008	0.0001
Coef. of Variation:	0.13	0.77
Coef. of Skewness:	-2.44	0.71
Root Mean Square:	0.0009	0.02
Mean Square:	7.63E-007	0.0003

Complete Spatial Randomness

Lambda: 976432.64
Clark and Evans: 1.71
Skellam: 238.77

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

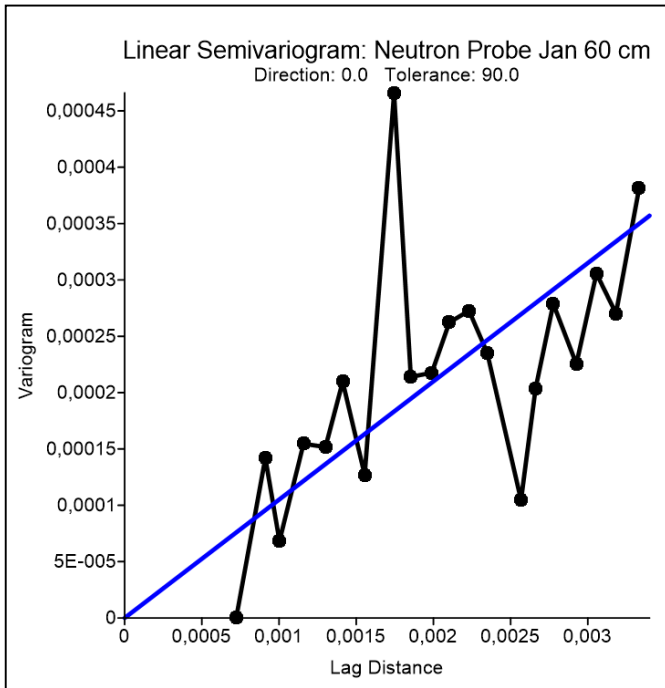


Figure 56: Linear Semi-variogram: Neutron probe January 60 cm.

Variogram Grid Report: Neutron probe January 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 41
Original Data: 41
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.08
25%-tile:	-26.97	26.84	0.09
Median:	-26.97	26.84	0.1
75%-tile:	-26.97	26.84	0.12
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.1
Range:	0.007	0.007	0.05
Interquartile Range:	0.003	0.003	0.03
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.1
Standard Deviation:	0.002	0.002	0.02
Variance:	3.42E-006	4.11E-006	0.0003
Coef. of Variation:			0.16
Coef. of Skewness:			0.031

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	11.14	7.23	106.56
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.01	-0.005	-8.71
Residual:	38	0.01	0.0005	
Total:	40	0.01		

Coefficient of Multiple Determination (R^2): -0.85

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	0
25%-tile:	0.0009	0.005
Median:	0.0009	0.009
75%-tile:	0.0009	0.01
Maximum:	0.001	0.03
Midrange:	0.0009	0.02
Range:	0.0003	0.03
Interquartile Range:	3.48E-005	0.01
Median Abs. Deviation:	2.14E-005	0.005
Mean:	0.0009	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	6.12E-005	0.009
Variance:	3.75E-009	7.73
Coef. of Variation:	0.07	0.81
Coef. of Skewness:	-1.24	1.09
Root Mean Square:	0.0009	0.01
Mean Square:	8.24E-007	0.0002

Complete Spatial Randomness

Lambda: 784975.26
Clark and Evans: 1.61
Skellam: 166.7

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

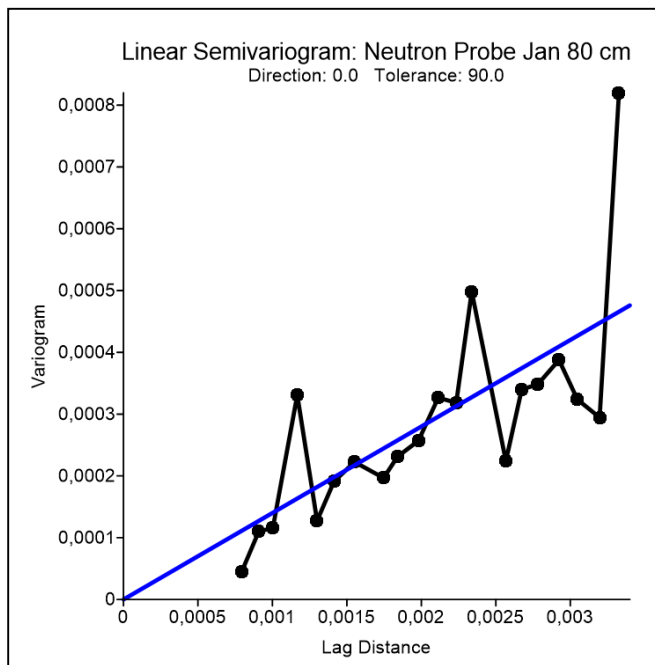


Figure 57: Linear Semi-variogram: Neutron probe January 80 cm.

Variogram Grid Report: Neutron probe January 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 36
Original Data: 36
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.09
25%-tile:	-26.97	26.84	0.1
Median:	-26.98	26.84	0.12
75%-tile:	-26.98	26.84	0.13
Maximum:	-26.98	26.84	0.15
Midrange:	-26.97	26.84	0.12
Range:	0.007	0.007	0.06
Interquartile Range:	0.003	0.004	0.03
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.12
Trim Mean (10%):	-26.97	26.84	0.11
Standard Deviation:	0.002	0.002	0.018
Variance:	3.7E-006	4.15E-006	0.0003
Coef. of Variation:			0.16
Coef. of Skewness:			-0.09

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.65	-0.94	-19.11
Standard Deviation:	0.81	0.76	25.33

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0007	2.31
Residual:	33	0.01	0.0003	
Total:	35	0.01		

Coefficient of Multiple Determination (R^2): 0.12

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.0004
25%-tile:	0.0009	0.009
Median:	0.0009	0.01
75%-tile:	0.0009	0.017
Maximum:	0.002	0.03
Midrange:	0.001	0.01
Range:	0.001	0.03
Interquartile Range:	5.33E-005	0.008
Median Abs. Deviation:	2.65E-005	0.004
Mean:	0.00097	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0002	0.007
Variance:	3.6E-008	4.97E-005
Coef. of Variation:	0.2	0.58
Coef. of Skewness:	4.68	0.46
Root Mean Square:	0.0014	0.014
Mean Square:	9.21E-007	0.0002

Complete Spatial Randomness

Lambda: 689246.57
Clark and Evans: 1.56
Skellam: 143.6

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

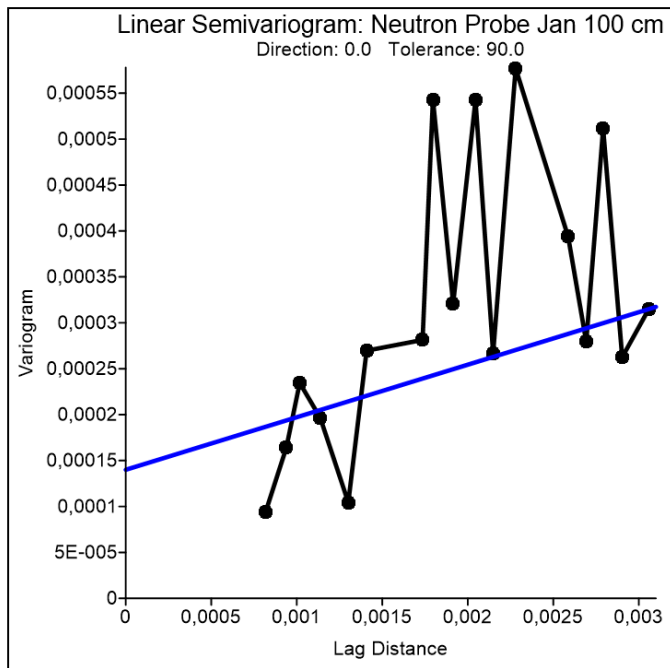


Figure 58: Linear Semi-variogram: Neutron probe January 100 cm.

Variogram Grid Report: Neutron probe January 100cm

Variogram Grid

Maximum Lag Distance: 0.0031
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 24
Original Data: 24
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.09
25%-tile:	-26.97	26.84	0.1
Median:	-26.97	26.84	0.13
75%-tile:	-26.97	26.84	0.14
Maximum:	-26.97	26.84	0.15
Midrange:	-26.97	26.84	0.12
Range:	0.007	0.006	0.06
Interquartile Range:	0.004	0.003	0.03
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.12
Trim Mean (10%):	-26.97	26.84	0.12
Standard Deviation:	0.002	0.002	0.02
Variance:	4.58E-006	3.12E-006	0.0004
Coef. of Variation:			0.16
Coef. of Skewness:			-0.29

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	93.57	39.17	1472.4
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.05	-0.03	-9.07
Residual:	21	0.06	0.003	
Total:	23	0.008		

Coefficient of Multiple Determination (R^2): -6.34

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0
25%-tile:	0.0008	0.007
Median:	0.0009	0.01
75%-tile:	0.001	0.02
Maximum:	0.002	0.04
Midrange:	0.001	0.02
Range:	0.001	0.04
Interquartile Range:	0.0001	0.01
Median Abs. Deviation:	3.63E-005	0.005
Mean:	0.001	0.02
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0003	0.01
Variance:	8.21E-008	0.0001
Coef. of Variation:	0.29	0.71
Coef. of Skewness:	2.6	0.96
Root Mean Square:	0.001	0.02
Mean Square:	1.07E-006	0.0004

Complete Spatial Randomness

Lambda: 547256.14
Clark and Evans: 1.47
Skellam: 88.48

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

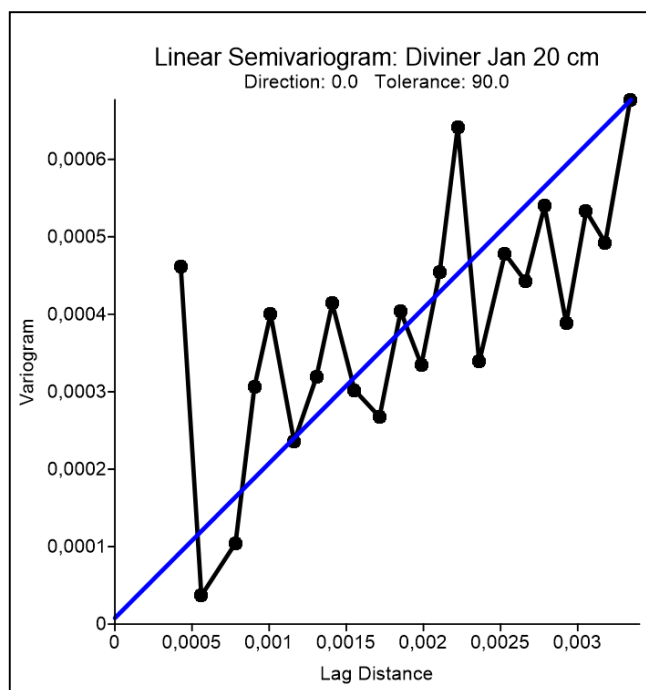


Figure 59: Linear Semi-variogram: Diviner January 20 cm.

Variogram Grid Report: Diviner January 20 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 55
Original Data: 55
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.06
Median:	-26.97	26.84	0.07
75%-tile:	-26.97	26.842	0.08
Maximum:	-26.97	26.844	0.134
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.11
Interquartile Range:	0.004	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.07
Trim Mean (10%):	-26.97	26.84	0.07
Standard Deviation:	0.002	0.002	0.02
Variance:	4.06E-006	4.336E-006	0.0004
Coef. of Variation:			0.31
Coef. of Skewness:			0.56

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.28	-0.85	15.42
Standard Deviation	0.93	0.9	34.71

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0004	0.0002	0.49
Residual:	52	0.02	0.0004	
Total:	54	0.02		

Coefficient of Multiple Determination (R^2): 0.02

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0001
25%-tile:	0.0001	0.01
Median:	0.0001	0.02
75%-tile:	0.0009	0.03
Maximum:	0.001	0.07
Midrange:	0.001	0.04
Range:	0.001	0.08
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	4.014E-005	0.01
Mean:	0.001	0.02
Trim Mean (10%):	0.001	0.02
Standard Deviation:	0.0001	0.01
Variance:	1.43E-008	0.0002
Coef. of Variation:	0.14	0.75
Coef. of Skewness:	-2.09	1.37
Root Mean Square:	0.0009	0.02
Mean Square:	7.42E-007	0.0006

Complete Spatial Randomness

Lambda: 1053015.59
Clark and Evans: 1.75
Skellam: 270.1

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

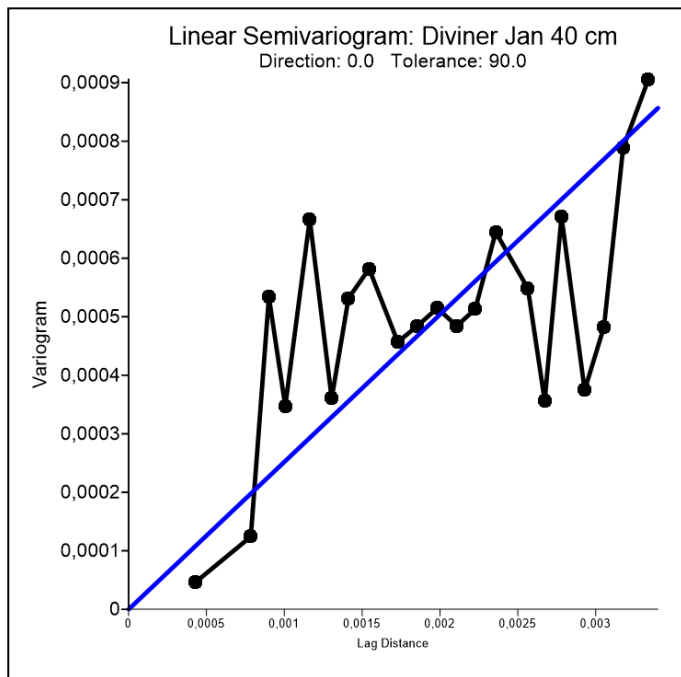


Figure 60: Linear Semi-variogram: Diviner January 40 cm.

Variogram Grid Report: Diviner January 40 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 51
Original Data: 51
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.09
Maximum:	-26.97	26.84	0.14
Midrange:	-26.97	26.84	0.09
Range:	0.007	0.007	0.1
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.09
Trim Mean (10%):	-26.97	26.84	0.09
Standard Deviation:	0.002	0.002	0.02
Variance:	3.8E-006	4.26E-006	0.001
Coef. of Variation:			0.267
Coef. of Skewness:			0.22

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-2.35	-0.94	-38.07
Standard Deviation:	1.5	1.42	54.89

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0007	1.41
Residual:	48	0.03	0.001	
Total:	50	0.03		

Coefficient of Multiple Determination (R^2): 0.06

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0001
25%-tile:	0.001	0.005
Median:	0.001	0.01
75%-tile:	0.001	0.03
Maximum:	0.001	0.09
Midrange:	0.001	0.05
Range:	0.001	0.09
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	5.24E-005	0.01
Mean:	0.001	0.02
Trim Mean (10%):	0.001	0.02
Standard Deviation:	0.0001	0.02
Variance:	1.21E-008	0.0005
Coef. of Variation:	0.13	1.1
Coef. of Skewness:	-2.44	1.5
Root Mean Square:	0.001	0.03
Mean Square:	7.63E-007	0.001

Complete Spatial Randomness

Lambda: 976432.64
Clark and Evans: 1.71
Skellam: 238.78

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

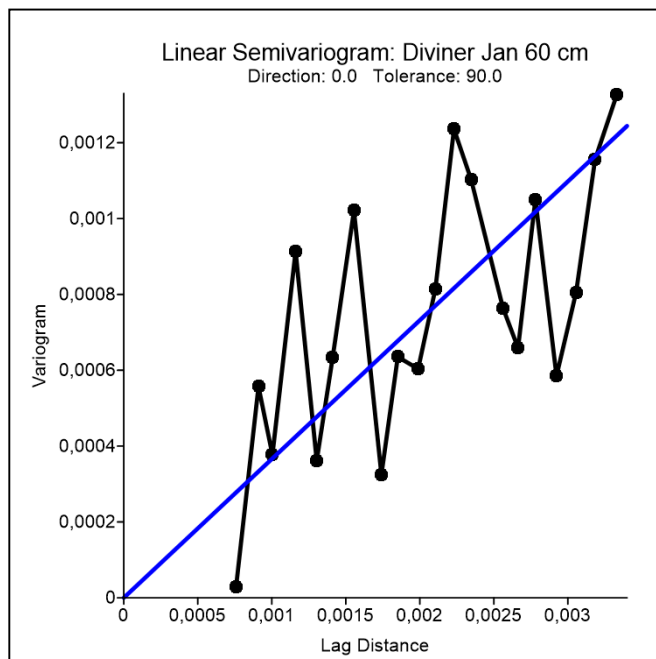


Figure 61: Linear Semi-variogram: Diviner January 60 cm.

Variogram Grid Report: Diviner January 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 42
Original Data: 42
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.08
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.11
Maximum:	-26.97	26.84	0.14
Midrange:	-26.97	26.84	0.09
Range:	0.007	0.007	0.1
Interquartile Range:	0.003	0.003	0.03
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.097
Trim Mean (10%):	-26.97	26.84	0.096
Standard Deviation:	0.0019	0.002	0.028
Variance:	3.44E-006	4.071E-006	0.001
Coef. of Variation:			0.29
Coef. of Skewness:			0.05

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	2.2	0.16	55.09
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.001	-0.0005	-0.6
Residual:	39	0.03	0.0008	
Total:	41	0.03		

Coefficient of Multiple Determination (R^2): -0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	0.0008
25%-tile:	0.0008	0.006
Median:	0.0009	0.009
75%-tile:	0.0009	0.02
Maximum:	0.001	0.1
Midrange:	0.0009	0.05
Range:	0.0003	0.1
Interquartile Range:	8.96E-005	0.02
Median Abs. Deviation:	2.421E-005	0.01
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	6.39E-005	0.025
Variance:	4.08E-009	0.0006
Coef. of Variation:	0.07	1.3
Coef. of Skewness:	-1.02	2.14
Root Mean Square:	0.0009	0.03
Mean Square:	8.11E-007	0.001

Complete Spatial Randomness

Lambda: 804120.99
Clark and Evans: 1.61
Skellam: 172.15

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

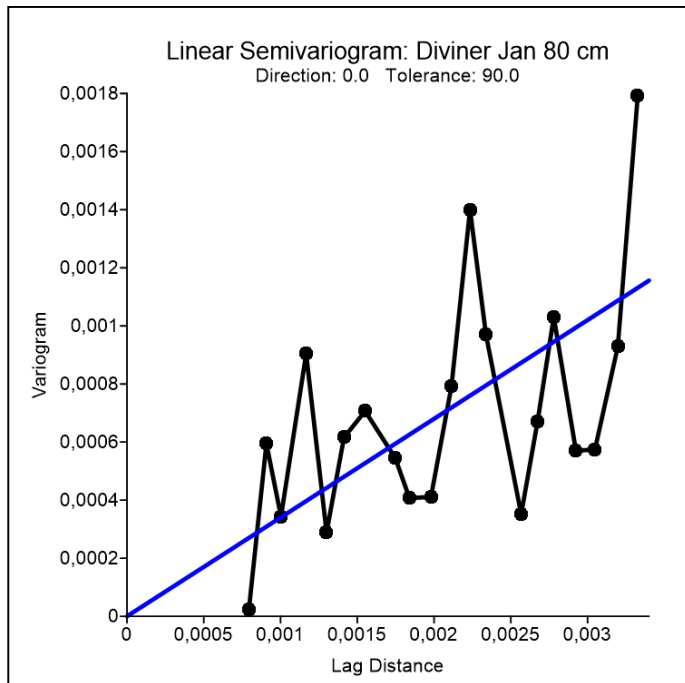


Figure 62: Linear Semi-variogram: Diviner January 80 cm.

Variogram Grid Report: Diviner January 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 36
Original Data: 36
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.038
25%-tile:	-26.97	26.84	0.09
Median:	-26.97	26.84	0.11
75%-tile:	-26.97	26.84	0.14
Maximum:	-26.98	26.84	0.15
Midrange:	-26.97	26.84	0.093
Range:	0.007	0.007	0.11
Interquartile Range:	0.003	0.004	0.02
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.11
Trim Mean (10%):	-26.97	26.84	0.11
Standard Deviation:	0.002	0.002	0.03
Variance:	3.7E-006	4.151E-006	0.001
Coef. of Variation:			0.26
Coef. of Skewness:			-0.58

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.54	-0.28	-33.9
Standard Deviation	1.3	1.23	40.82

ANOVA Table

Source	df	Sum of Sqr	Mean Sqr	F
Regression:	2	0.001	0.001	0.71
Residual:	33	0.03	0.001	
Total:	35	0.03		

Coefficient of Multiple Determination (R^2): 0.04

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.001	0.0001
25%-tile:	0.001	0.002
Median:	0.001	0.01
75%-tile:	0.001	0.02
Maximum:	0.0028	0.11
Midrange:	0.001	0.05
Range:	0.001	0.11
Interquartile Range:	5.33E-005	0.02
Median Abs. Deviation:	2.65E-005	0.01
Mean:	0.001	0.02
Trim Mean (10%):	0.001	0.01
Standard Deviation:	0.0002	0.03
Variance:	3.63E-008	0.001
Coef. of Variation:	0.2	1.46
Coef. of Skewness:	4.68	2.478
Root Mean Square:	0.001	0.03
Mean Square:	9.21E-007	0.001

Complete Spatial Randomness

Lambda: 689246.57
Clark and Evans: 1.56
Skellam: 143.6

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

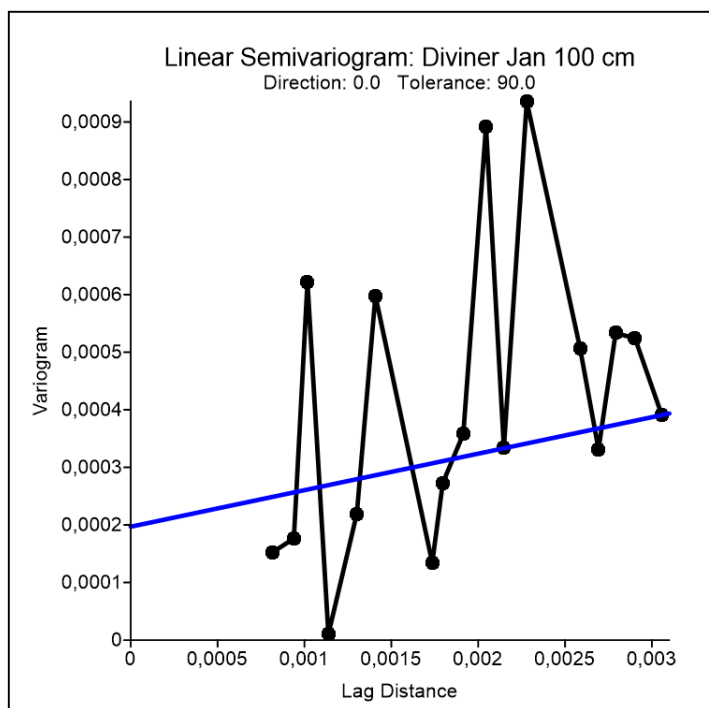


Figure 63: Linear Semi-variogram: Diviner January 100 cm.

Variogram Grid Report: Diviner January 100cm

Variogram Grid

Maximum Lag Distance: 0.0031
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 24
Original Data: 24
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.062
25%-tile:	-26.97	26.84	0.1
Median:	-26.97	26.84	0.11
75%-tile:	-26.97	26.84	0.14
Maximum:	-26.97	26.84	0.15
Midrange:	-26.97	26.84	0.1
Range:	0.08	0.01	0.09
Interquartile Range:	0.004	0.003	0.04
Median Abs. Deviation:	0.001	0.001	0.02
Mean:	-26.97	26.84	0.11
Trim Mean (10%):	-26.97	26.84	0.11
Standard Deviation:	0.002	0.002	0.02
Variance:	4.58E-006	3.12E-006	0.001
Coef. of Variation:			0.2
Coef. of Skewness:			-0.35

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	74.62	-28.71	2783.41
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.04	-0.02	-8.26
Residual:	21	0.06	0.003	
Total:	23	0.01		

Coefficient of Multiple Determination (R^2): -3.69

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.001
25%-tile:	0.0009	0.007
Median:	0.0009	0.02
75%-tile:	0.001	0.02
Maximum:	0.002	0.07
Midrange:	0.001	0.036
Range:	0.001	0.07
Interquartile Range:	0.0001	0.01
Median Abs. Deviation:	3.63E-005	0.01
Mean:	0.001	0.02
Trim Mean (10%):	0.001	0.01
Standard Deviation:	0.0003	0.01
Variance:	8.21E-008	0.0002
Coef. of Variation:	0.29	0.87
Coef. of Skewness:	2.6	2.15
Root Mean Square:	0.001	0.02
Mean Square:	1.07E-006	0.0005

Complete Spatial Randomness

Lambda: 547256.14
Clark and Evans: 1.47
Skellam: 88.48

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

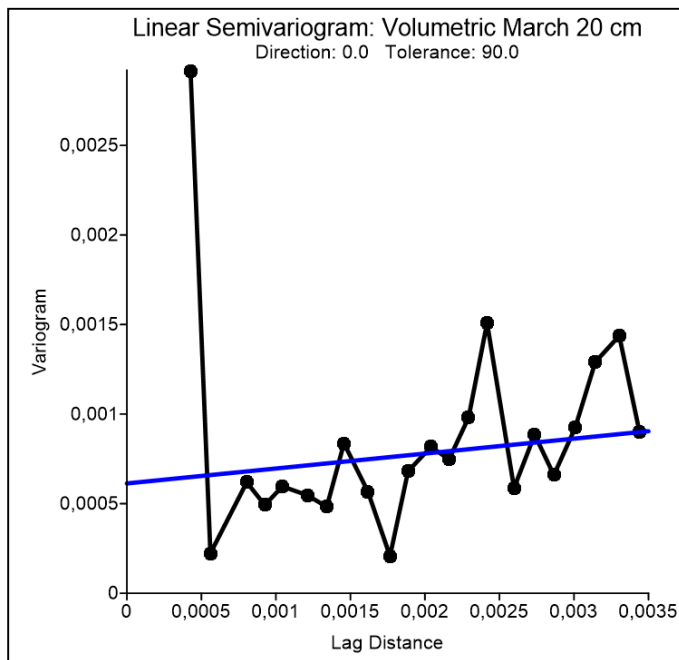


Figure 64: Linear Semi-variogram: Volumetric March 20 cm.

Variogram Grid Report: Volumetric March 20 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 57
Original Data: 57
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.834	0.009
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.05
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.06
Range:	0.007	0.008	0.11
Interquartile Range:	0.003	0.003	0.05
Median Abs. Deviation:	0.002	0.002	0.03
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.84	0.05
Standard Deviation:	0.002	0.002	0.03
Variance:	3.84E-006	4.57E-006	0.0009
Coef. of Variation:			0.55
Coef. of Skewness:			0.25

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.83	-3.93	56.2
Standard Deviation:	1.36	1.24	48.8

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0093	0.005	5.81
Residual:	54	0.049	0.0008	
Total:	56	0.05		

Coefficient of Multiple Determination (R^2): 0.18

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0004
25%-tile:	0.0008	0.005
Median:	0.00089	0.02
75%-tile:	0.0009	0.04
Maximum:	0.001	0.08
Midrange:	0.0007	0.034
Range:	0.0006	0.08
Interquartile Range:	9.9E-005	0.04
Median Abs. Deviation:	4.33E-005	0.01
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.02
Variance:	1.38E-008	0.0006
Coef. of Variation:	0.14	1.0
Coef. of Skewness:	-2.2	1.0
Root Mean Square:	0.0009	0.03
Mean Square:	7.48E-007	0.001

Complete Spatial Randomness

Lambda: 983006.64
Clark and Evans: 1.7
Skellam: 263.36

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

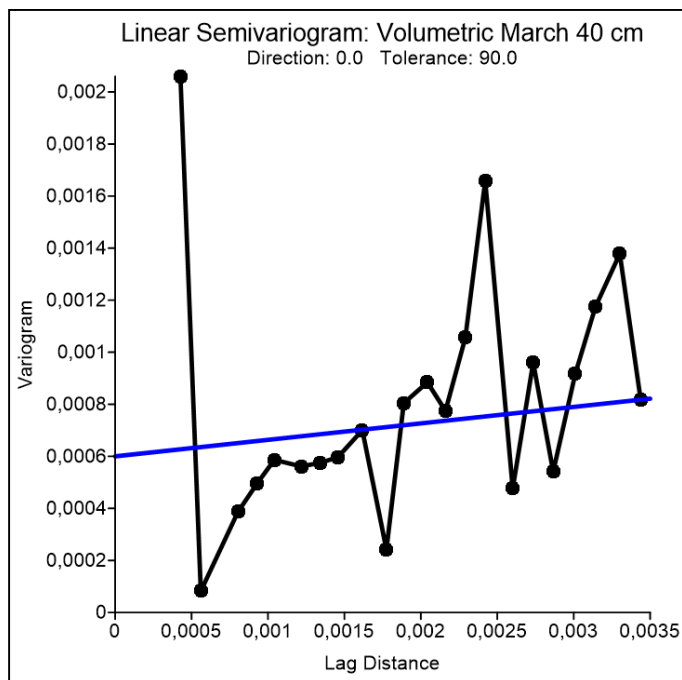


Figure 65: Linear Semi-variogram: Volumetric March 40 cm.

Variogram Grid Report: Volumetric March 40 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 53
Original Data: 53
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.01
25%-tile:	-26.97	26.84	0.04
Median:	-26.97	26.84	0.06
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.008	0.11
Interquartile Range:	0.003	0.003	0.05
Median Abs. Deviation:	0.002	0.002	0.02
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.84	0.06
Standard Deviation:	0.002	0.002	0.03
Variance:	3.59E-006	4.44E-006	0.0008
Coef. of Variation:			0.48
Coef. of Skewness:			0.059

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.53	-0.64	3.09
Standard Deviation:	0.76	0.69	27.31

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0006	0.66
Residual:	50	0.04	0.0009	
Total:	52	0.04		

Coefficient of Multiple Determination (R^2): 0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0002
25%-tile:	0.0008	0.01
Median:	0.0009	0.02
75%-tile:	0.0009	0.03
Maximum:	0.001	0.09
Midrange:	0.0009	0.04
Range:	0.0009	0.09
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	3.76E-005	0.01
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.02
Variance:	1.9E-008	0.0004
Coef. of Variation:	0.16	0.78
Coef. of Skewness:	-0.82	1.24
Root Mean Square:	0.0009	0.03
Mean Square:	7.64E-007	0.001

Complete Spatial Randomness

Lambda: 914023.71
Clark and Evans: 1.65
Skellam: 232.53

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

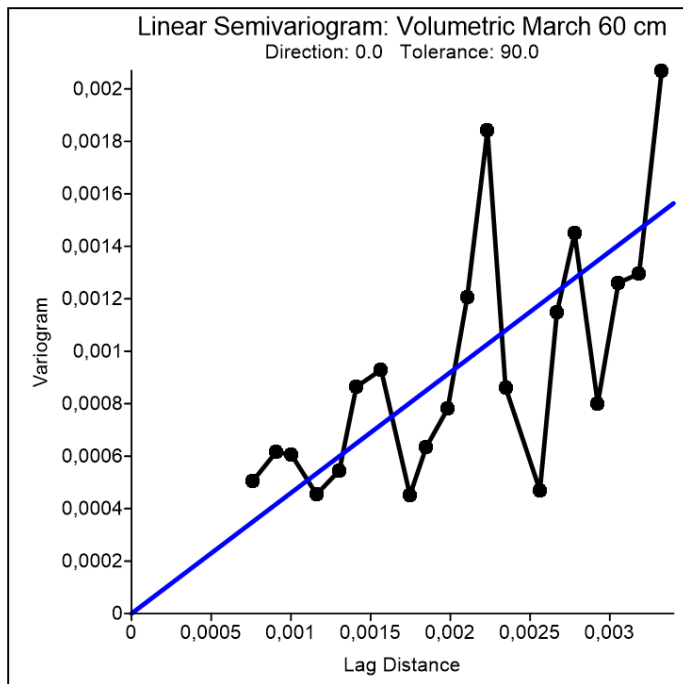


Figure 66: Linear Semi-variogram: Volumetric March 60 cm.

Variogram Grid Report: Volumetric March 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 42
Original Data: 42
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.005
25%-tile:	-26.97	26.84	0.06
Median:	-26.97	26.84	0.08
75%-tile:	-26.97	26.84	0.09
Maximum:	-26.97	26.84	0.15
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.15
Interquartile Range:	0.0027	0.003	0.03
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.002	0.002	0.03
Variance:	3.38E-006	3.94E-006	0.001
Coef. of Variation:			0.41
Coef. of Skewness:			0.13

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.97	-0.9	-1.69
Standard Deviation:	1.18	1.094	38.64

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0006	0.56
Residual:	39	0.04	0.001	
Total:	41	0.04		

Coefficient of Multiple Determination (R^2): 0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	6.15E-005
25%-tile:	0.0008	0.02
Median:	0.0009	0.03
75%-tile:	0.0009	0.04
Maximum:	0.0018	0.08
Midrange:	0.0009	0.04
Range:	0.0003	0.08
Interquartile Range:	9.28E-005	0.03
Median Abs. Deviation:	3.22E-005	0.02
Mean:	0.0009	0.03
Trim Mean (10%):	0.0009	0.03
Standard Deviation:	6.59E-005	0.02
Variance:	4.35E-009	0.0004
Coef. of Variation:	0.07	0.69
Coef. of Skewness:	-0.81	0.35
Root Mean Square:	0.0009	0.03
Mean Square:	8.04E-007	0.001

Complete Spatial Randomness

Lambda: 804120.99
Clark and Evans: 1.6
Skellam: 170.59

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

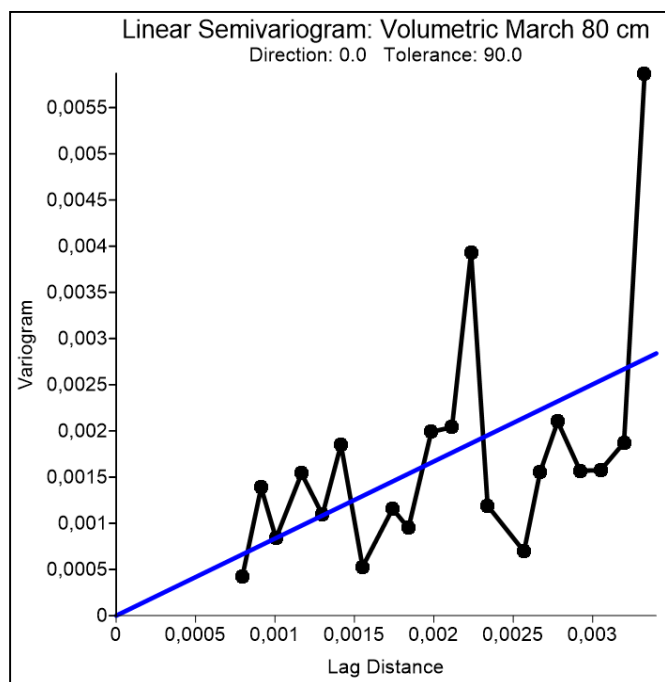


Figure 67: Linear Semi-variogram: Volumetric March 80 cm.

Variogram Grid Report: Volumetric March 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 35
Original Data: 35
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.02
25%-tile:	-26.97	26.84	0.08
Median:	-26.97	26.84	0.1
75%-tile:	-26.97	26.84	0.12
Maximum:	-26.97	26.84	0.22
Midrange:	-26.97	26.84	0.12
Range:	0.007	0.007	0.2
Interquartile Range:	0.003	0.004	0.04
Median Abs. Deviation:	0.002	0.002	0.02
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.1
Standard Deviation:	0.002	0.002	0.04
Variance:	3.79E-006	4.24E-006	0.002
Coef. of Variation:			0.42
Coef. of Skewness:			0.34

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-5.51	-5.06	-12.76
Standard Deviation:	3.49	3.3	109.83

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.006	0.003	1.88
Residual:	32	0.05	0.002	
Total:	34	0.06		

Coefficient of Multiple Determination (R^2): 0.11

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	1.45E-005
25%-tile:	0.0009	0.008
Median:	0.00093	0.02
75%-tile:	0.0009	0.04
Maximum:	0.002	0.07
Midrange:	0.001	0.04
Range:	0.001	0.07
Interquartile Range:	4.21E-005	0.03
Median Abs. Deviation:	2.95E-005	0.02
Mean:	0.0001	0.03
Trim Mean (10%):	0.0009	0.03
Standard Deviation:	0.0002	0.02
Variance:	3.86E-008	0.0004
Coef. of Variation:	0.21	0.85
Coef. of Skewness:	4.24	0.61
Root Mean Square:	0.001	0.04
Mean Square:	9.51E-007	0.001

Complete Spatial Randomness

Lambda: 670100.83
Clark and Evans: 1.56
Skellam: 140.15

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

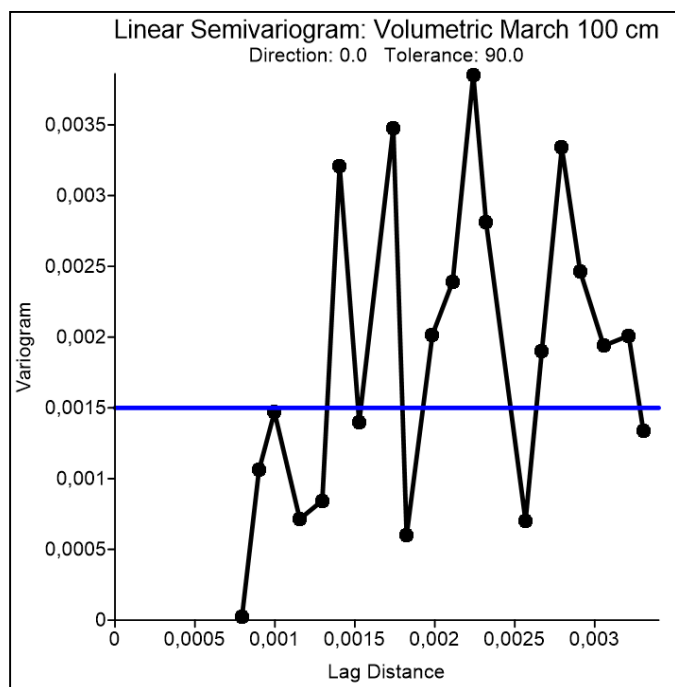


Figure 68: Linear Semi-variogram: Volumetric March 100 cm.

Variogram Grid Report: Volumetric March 100 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 28
Original Data: 28
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.01
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.12
75%-tile:	-26.97	26.84	0.13
Maximum:	-26.97	26.84	0.2
Midrange:	-26.97	26.84	0.11
Range:	0.007	0.007	0.19
Interquartile Range:	0.003	0.004	0.05
Median Abs. Deviation:	0.001	0.002	0.03
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.1
Standard Deviation:	0.002	0.002	0.05
Variance:	4.16E-006	4.4E-006	0.002
Coef. of Variation:			0.43
Coef. of Skewness:			0.24

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.26	-0.85	15.75
Standard Deviation:	1.41	1.38	46.39

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0008	0.0004	0.19
Residual:	25	0.05	0.002	
Total:	27	0.06		

Coefficient of Multiple Determination (R^2): 0.01

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.004
25%-tile:	0.0009	0.007
Median:	0.0009	0.02
75%-tile:	0.001	0.04
Maximum:	0.002	0.09
Midrange:	0.001	0.05
Range:	0.001	0.09
Interquartile Range:	7.87E-005	0.04
Median Abs. Deviation:	4.61E-005	0.01
Mean:	0.001	0.03
Trim Mean (10%):	0.0009	0.03
Standard Deviation:	0.0003	0.03
Variance:	7.12E-008	0.0008
Coef. of Variation:	0.27	0.9
Coef. of Skewness:	2.93	1.18
Root Mean Square:	0.001	0.04
Mean Square:	1.03E-006	0.002

Complete Spatial Randomness

Lambda: 536080.66
Clark and Evans: 1.44
Skellam: 97.14

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

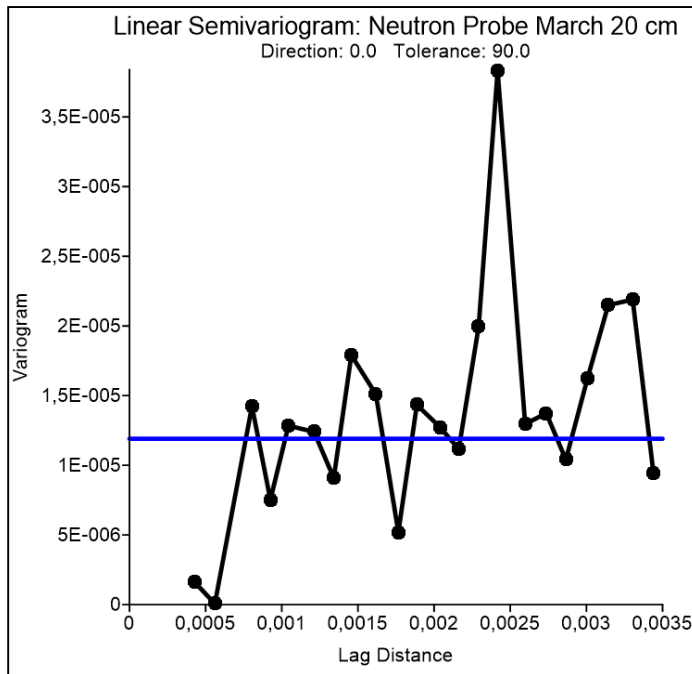


Figure 69: Linear Semi-variogram: Neutron probe March 20 cm.

Variogram Grid Report: Neutron probe March 20 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 57

Original Data: 57
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.04
Median:	-26.97	26.84	0.04
75%-tile:	-26.97	26.84	0.04
Maximum:	-26.97	26.84	0.05
Midrange:	-26.97	26.84	0.05
Range:	0.007	0.008	0.02
Interquartile Range:	0.003	0.003	0.003
Median Abs. Deviation:	0.002	0.002	0.002
Mean:	-26.97	26.84	0.04
Trim Mean (10%):	-26.97	26.84	0.04
Standard Deviation:	0.002	0.002	0.004
Variance:	3.84E-006	4.57E-006	1.21E-005
Coef. of Variation:			0.09
Coef. of Skewness:			1.88

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.15	-0.26	3.2
Standard Deviation:	0.16	0.15	5.88

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	4.36E-005	2.18E-005	1.85
Residual:	54	0.0006	1.17E-005	
Total:	56	0.0007		

Coefficient of Multiple Determination (R^2): 0.06

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	8.0 E-005
25%-tile:	0.0008	0.0009
Median:	0.0009	0.002
75%-tile:	0.0009	0.003
Maximum:	0.001	0.02
Midrange:	0.0007	0.008
Range:	0.0006	0.017
Interquartile Range:	9.9E-005	0.0019
Median Abs. Deviation:	4.33E-005	0.001
Mean:	0.0009	0.003
Trim Mean (10%):	0.0009	0.002
Standard Deviation:	0.0002	0.003
Variance:	1.38E-008	1.19E-005
Coef. of Variation:	0.14	1.21
Coef. of Skewness:	-2.196	2.4
Root Mean Square:	0.0009	0.004
Mean Square:	7.48E-007	1.98E-005

Complete Spatial Randomness

Lambda: 983006.64
Clark and Evans: 1.7
Skellam: 263.36

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

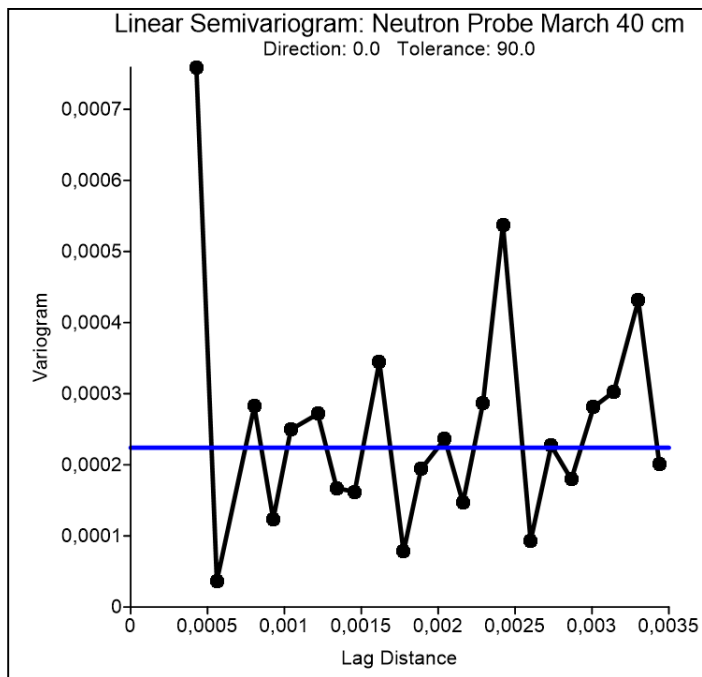


Figure 70: Linear Semi-variogram: Neutron probe March 40 cm.

Variogram Grid Report: Neutron probe March 40 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 53
Original Data: 53
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.05
Median:	-26.97	26.84	0.06
75%-tile:	-26.97	26.84	0.07
Maximum:	-26.97	26.84	0.11
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.008	0.06
Interquartile Range:	0.002	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.07
Trim Mean (10%):	-26.97	26.84	0.06
Standard Deviation:	0.002	0.002	0.02
Variance:	3.59E-006	4.44E-006	0.0002
Coef. of Variation:			0.24
Coef. of Skewness:			0.72

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.3	-0.43	2.45
Standard Deviation:	0.41	0.37	14.56

ANOVA Table

Source	df	Sum of Sqs	Mean Sqr	F
Regression:	2	0.0005	0.0003	1.03
Residual:	50	0.01	0.0002	
Total:	52	0.01		

Coefficient of Multiple Determination (R^2): 0.04

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	4.0E-005
25%-tile:	0.0008	0.004
Median:	0.0009	0.009
75%-tile:	0.0009	0.014
Maximum:	0.0013	0.05
Midrange:	0.0009	0.03
Range:	0.0009	0.05
Interquartile Range:	0.0001	0.009
Median Abs. Deviation:	3.76E-005	0.005
Mean:	0.0009	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0001	0.01
Variance:	1.9E-008	0.0002
Coef. of Variation:	0.16	1.028
Coef. of Skewness:	-0.82	1.68
Root Mean Square:	0.0009	0.02
Mean Square:	7.64E-007	0.0003

Complete Spatial Randomness

Lambda: 914023.71
Clark and Evans: 1.65
Skellam: 232.53

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

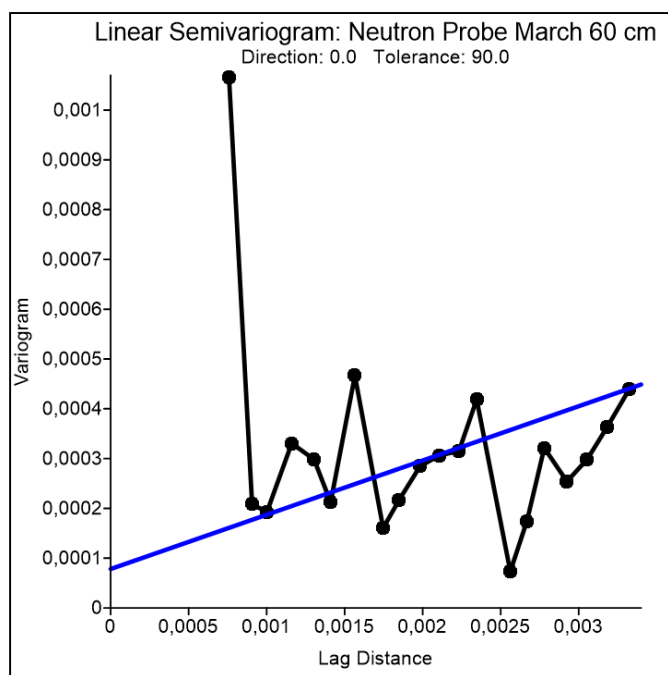


Figure 71: Linear Semi-variogram: Neutron probe March 60 cm.

Variogram Grid Report: Neutron probe March 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 42
Original Data: 42
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.05
25%-tile:	-26.97	26.84	0.06
Median:	-26.97	26.84	0.06
75%-tile:	-26.97	26.84	0.09
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.06
Interquartile Range:	0.003	0.003	0.03
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.002	0.002	0.02
Variance:	3.38E-006	3.94E-006	0.0003
Coef. of Variation:			0.22
Coef. of Skewness:			0.37

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.68	-0.74	1.66
Standard Deviation:	0.62	0.57	20.24

ANOVA Table

Source	df	Sum of Sqs	Mean Sqr	F
Regression:	2	0.0007	0.0004	1.19
Residual:	39	0.01	0.0003	
Total:	41	0.01		

Coefficient of Multiple Determination (R^2): 0.06

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	0
25%-tile:	0.0008	0.01
Median:	0.0009	0.02
75%-tile:	0.0009	0.02
Maximum:	0.001	0.06
Midrange:	0.0009	0.03
Range:	0.0003	0.06
Interquartile Range:	9.28E-005	0.01
Median Abs. Deviation:	3.22E-005	0.005
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	6.59E-005	0.015
Variance:	4.35E-009	0.0002
Coef. of Variation:	0.07	0.8
Coef. of Skewness:	-0.8	1.46
Root Mean Square:	0.0009	0.02
Mean Square:	8.04E-007	0.0006

Complete Spatial Randomness

Lambda: 804120.99
Clark and Evans: 1.6
Skellam: 170.59

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

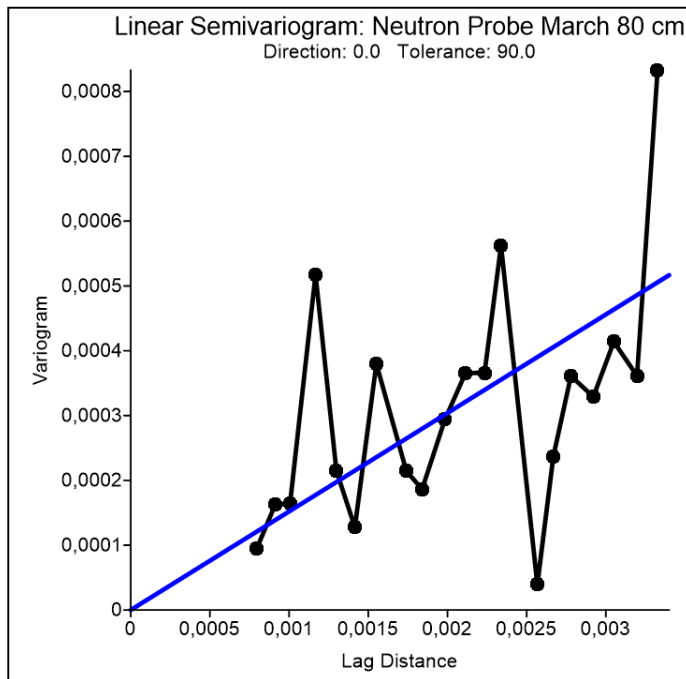


Figure 72: Linear Semi-variogram: Neutron probe March 80 cm.

Variogram Grid Report: Neutron probe March 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 35
Original Data: 35
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.06
25%-tile:	-26.97	26.84	0.08
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.14
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.1
Range:	0.007	0.007	0.07
Interquartile Range:	0.003	0.004	0.02
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.09
Standard Deviation:	0.002	0.002	0.02
Variance:	3.79E-006	4.24E-006	0.0003
Coef. of Variation:			0.19
Coef. of Skewness:			0.32

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-4.37	-3.53	-23.18
Standard Deviation:	1.29	1.22	40.68

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.004	0.002	7.77
Residual:	32	0.008	0.0002	
Total:	34	0.01		

Coefficient of Multiple Determination (R^2): 0.33

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.0007
25%-tile:	0.0009	0.006
Median:	0.0009	0.01
75%-tile:	0.0009	0.02
Maximum:	0.002	0.03
Midrange:	0.001	0.02
Range:	0.001	0.03
Interquartile Range:	4.21E-005	0.01
Median Abs. Deviation:	2.95E-005	0.005
Mean:	0.001	0.01
Trim Mean (10%):	0.001	0.01
Standard Deviation:	0.0002	0.008
Variance:	3.9E-008	7.14E-005
Coef. of Variation:	0.21	0.65
Coef. of Skewness:	4.24	0.32
Root Mean Square:	0.001	0.02
Mean Square:	9.51E-007	0.0002

Complete Spatial Randomness

Lambda: 67
Clark and Evans: 1.56
Skellam: 140.15

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

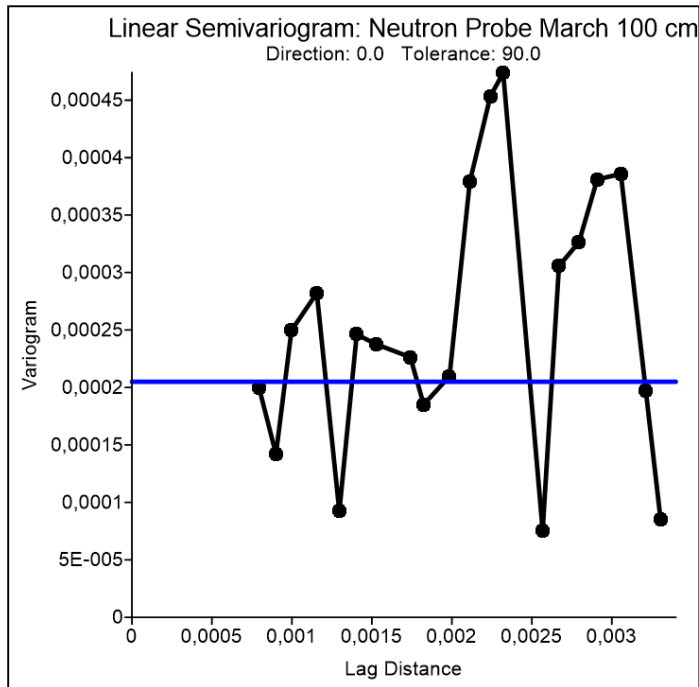


Figure 73: Linear Semi-variogram: Neutron probe March 100 cm.

Variogram Grid Report: Neutron probe March 100 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 28
Original Data: 28
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.07
25%-tile:	-26.97	26.84	0.09
Median:	-26.97	26.84	0.1
75%-tile:	-26.97	26.84	0.11
Maximum:	-26.97	26.84	0.14
Midrange:	-26.97	26.84	0.1
Range:	0.007	0.007	0.07
Interquartile Range:	0.003	0.004	0.02
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.1
Standard Deviation:	0.002	0.002	0.02
Variance:	4.162E-006	4.4E-006	0.0001
Coef. of Variation:			0.17
Coef. of Skewness:			0.008

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.36	-0.3	-1.56
Standard Deviation:	0.53	0.52	17.49

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0002	0.0001	0.33
Residual:	25	0.008	0.0003	
Total:	27	0.0086		

Coefficient of Multiple Determination (R^2): 0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.005
25%-tile:	0.0009	0.01
Median:	0.0009	0.02
75%-tile:	0.001	0.02
Maximum:	0.002	0.02
Midrange:	0.001	0.01
Range:	0.001	0.02
Interquartile Range:	7.87E-005	0.01
Median Abs. Deviation:	4.61E-005	0.005
Mean:	0.001	0.02
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0003	0.006
Variance:	7.12E-008	3.18E-005
Coef. of Variation:	0.27	0.37
Coef. of Skewness:	2.93	-0.28
Root Mean Square:	0.001	0.02
Mean Square:	1.02E-006	0.0003

Complete Spatial Randomness

Lambda: 536080.66
Clark and Evans: 1.44
Skellam: 97.14

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

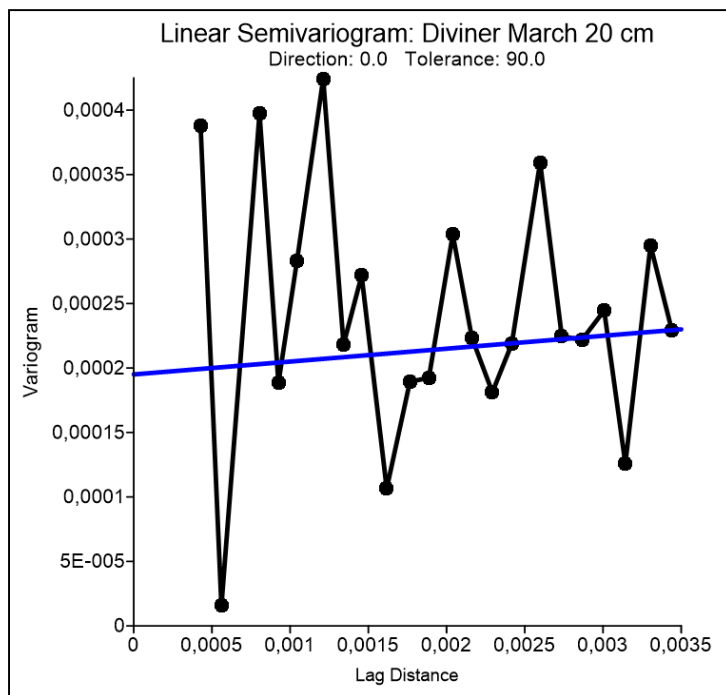


Figure 74: Linear Semi-variogram: Diviner March 20 cm.

Variogram Grid Report: Diviner March 20 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 57

Original Data: 57
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.05
Median:	-26.97	26.84	0.06
75%-tile:	-26.97	26.84	0.06
Maximum:	-26.97	26.84	0.11
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.008	0.08
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.008
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.84	0.05
Standard Deviation:	0.002	0.002	0.01
Variance:	3.84E-006	4.579E-006	0.0002
Coef. of Variation:			0.26
Coef. of Skewness:			0.69

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.03	-0.42	10.52
Standard Deviation:	0.69	0.63	24.83

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	9.06E-005	4.536E-005	0.22
Residual:	54	0.01	0.0002	
Total:	56	0.01		

Coefficient of Multiple Determination (R^2): 0.008

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0004
25%-tile:	0.0008	0.004
Median:	0.0009	0.01
75%-tile:	0.0009	0.018
Maximum:	0.001	0.07
Midrange:	0.0007	0.03
Range:	0.0006	0.07
Interquartile Range:	9.9E-005	0.01
Median Abs. Deviation:	4.33E-005	0.006
Mean:	0.0009	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0001	0.01
Variance:	1.38E-008	0.0002
Coef. of Variation:	0.14	1.07
Coef. of Skewness:	-2.2	2.0
Root Mean Square:	0.0009	0.02
Mean Square:	7.48E-007	0.0004

Complete Spatial Randomness

Lambda: 983006.64
Clark and Evans: 1.7
Skellam: 263.36

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

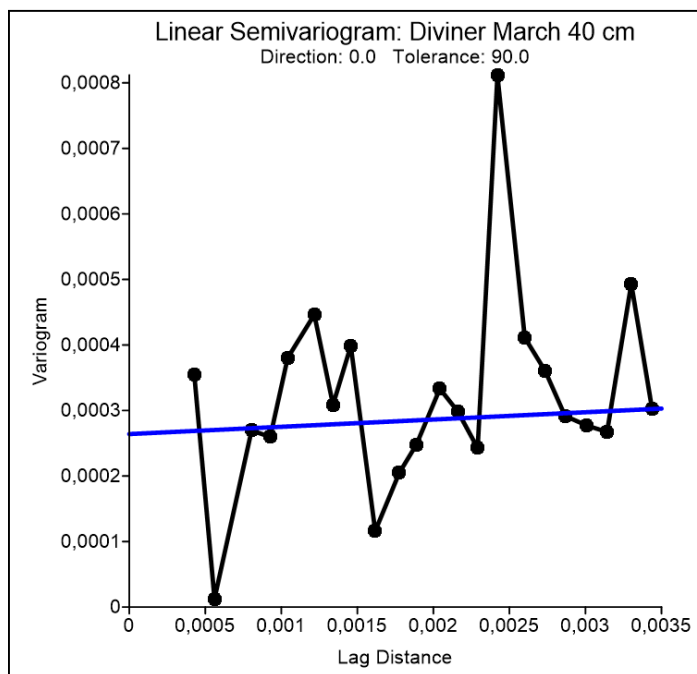


Figure 75: Linear Semi-variogram: Diviner March 40 cm.

Variogram Grid Report: Diviner March 40 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 53
Original Data: 53
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.06
Median:	-26.97	26.84	0.07
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.008	0.08
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.07
Trim Mean (10%):	-26.97	26.84	0.07
Standard Deviation:	0.0012	0.002	0.02
Variance:	3.59E-006	4.44E-006	0.0003
Coef. of Variation:			0.24
Coef. of Skewness:			0.54

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.06	0.08	-3.62
Standard Deviation:	0.45	0.4	16.02

ANOVA Table

Source	df	Sum of Sqs	Mean Sqr	F
Regression:	2	1.67E-005	8.33E-006	0.03
Residual:	50	0.01	0.0003	
Total:	52	0.01		

Coefficient of Multiple Determination (R^2): 0.001

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0003
25%-tile:	0.0008	0.009
Median:	0.0009	0.01
75%-tile:	0.0009	0.03
Maximum:	0.001	0.05
Midrange:	0.0009	0.02
Range:	0.0009	0.05
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	3.76E-005	0.009
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.01
Variance:	1.9E-008	0.0002
Coef. of Variation:	0.16	0.73
Coef. of Skewness:	-0.82	0.61
Root Mean Square:	0.0009	0.02
Mean Square:	7.64E-007	0.0005

Complete Spatial Randomness

Lambda: 914023.71
Clark and Evans: 1.65
Skellam: 232.53

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

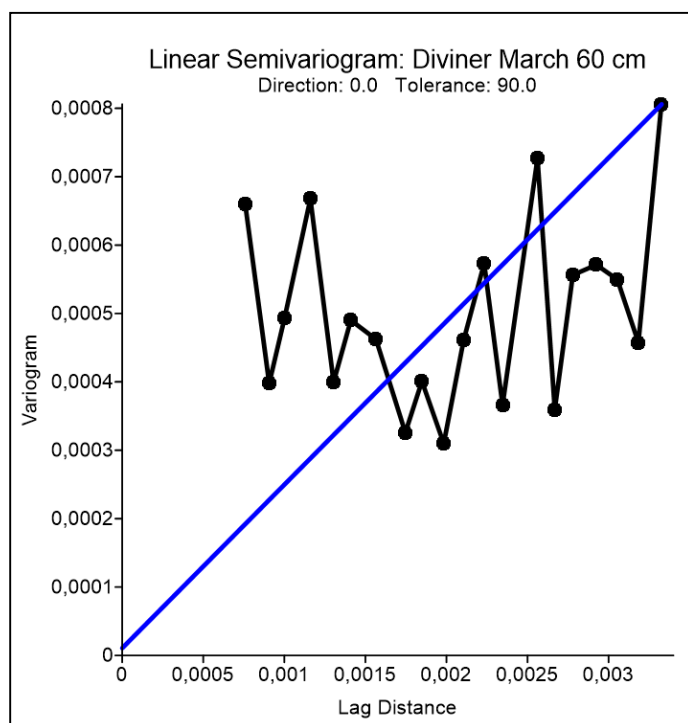


Figure 76: Linear Semi-variogram: Diviner March 60 cm.

Variogram Grid Report: Diviner March 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 42
Original Data: 42
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.08
75%-tile:	-26.97	26.84	0.1
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.1
Interquartile Range:	0.003	0.003	0.03
Median Abs. Deviation:	0.001	0.008	0.01
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.002	0.002	0.02
Variance:	3.38E-006	3.94E-006	0.0005
Coef. of Variation:			0.26
Coef. of Skewness:			-0.24

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.03	0.22	-6.71
Standard Deviation:	0.79	0.73	25.75

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	4.82E-005	2.41E-005	0.05
Residual:	39	0.02	0.0005	
Total:	41	0.02		

Coefficient of Multiple Determination (R^2): 0.003

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.001
25%-tile:	0.0008	0.004
Median:	0.0009	0.01
75%-tile:	0.0009	0.03
Maximum:	0.001	0.06
Midrange:	0.0009	0.03
Range:	0.0003	0.05
Interquartile Range:	9.28E-005	0.03
Median Abs. Deviation:	3.22E-005	0.01
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	6.59E-005	0.02
Variance:	4.35E-009	0.0004
Coef. of Variation:	0.07	0.92
Coef. of Skewness:	-0.81	0.71
Root Mean Square:	0.0009	0.03
Mean Square:	8.04E-007	0.0008

Complete Spatial Randomness

Lambda: 804120.99
Clark and Evans: 1.6
Skellam: 170.59

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

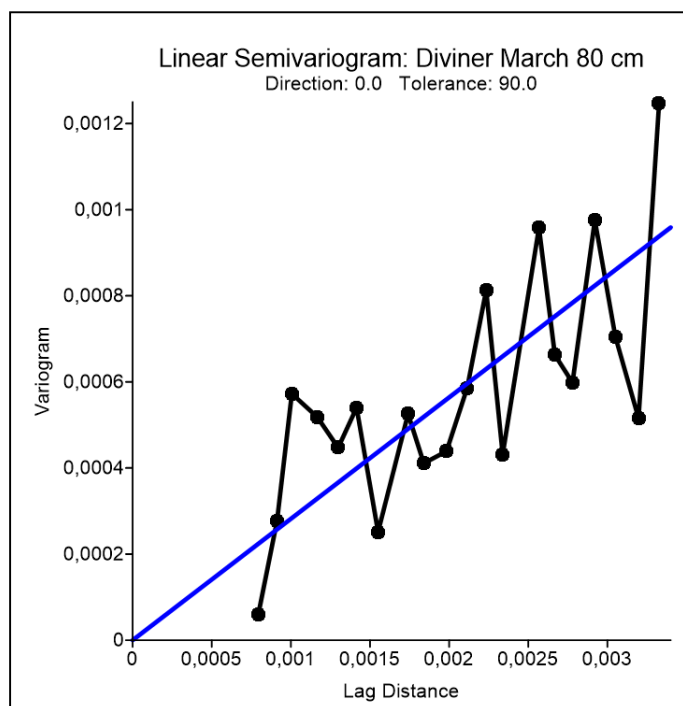


Figure 77: Linear Semi-variogram: Diviner March 80 cm.

Variogram Grid Report: Diviner March 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 35
Original Data: 35
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.08
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.1
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.1
Interquartile Range:	0.003	0.004	0.03
Median Abs. Deviation:	0.002	0.002	0.02
Mean:	-26.97	26.84	0.09
Trim Mean (10%):	-26.97	26.84	0.09
Standard Deviation:	0.002	0.002	0.02
Variance:	3.79E-006	4.24E-006	0.0006
Coef. of Variation:			0.27
Coef. of Skewness:			-0.41

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.07	0.9	-52.7
Standard Deviation:	2.08	1.97	65.45

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0004	0.0002	0.33
Residual:	32	0.02	0.0006	
Total:	34	0.02		

Coefficient of Multiple Determination (R^2): 0.02

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.0008
25%-tile:	0.0009	0.008
Median:	0.0009	0.01
75%-tile:	0.0009	0.03
Maximum:	0.002	0.1
Midrange:	0.001	0.05
Range:	0.001	0.1
Interquartile Range:	4.21E-005	0.02
Median Abs. Deviation:	2.95E-005	0.006
Mean:	0.001	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0002	0.02
Variance:	3.86E-008	0.0006
Coef. of Variation:	0.21	1.04
Coef. of Skewness:	4.24	1.98
Root Mean Square:	0.001	0.03
Mean Square:	9.51E-007	0.001

Complete Spatial Randomness

Lambda: 670100.83
Clark and Evans: 1.56
Skellam: 140.15

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

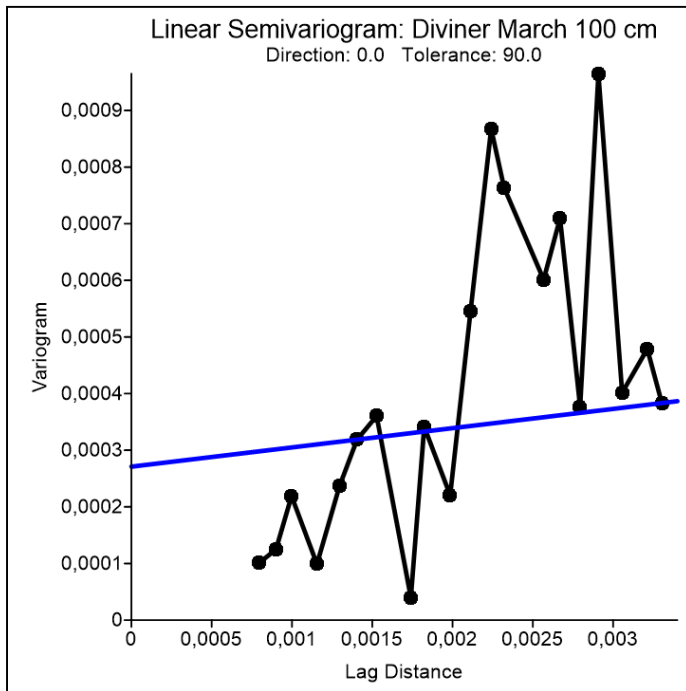


Figure 78: Linear Semi-variogram: Diviner March 100 cm.

Variogram Grid Report: Diviner March 100 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 28
Original Data: 28
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.05
25%-tile:	-26.97	26.84	0.09
Median:	-26.97	26.84	0.1
75%-tile:	-26.97	26.84	0.11
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.09
Range:	0.007	0.007	0.08
Interquartile Range:	0.003	0.004	0.03
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.1
Standard Deviation:	0.002	0.002	0.02
Variance:	4.16E-006	4.4E-006	0.0004
Coef. of Variation:			0.22
Coef. of Skewness:			-0.42

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.11	0.03	-3.44
Standard Deviation:	0.69	0.67	22.53

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	1.54E-005	7.71E-006	0.01
Residual:	25	0.013	0.0005	
Total:	27	0.013		

Coefficient of Multiple Determination (R^2): 0.001

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.001
25%-tile:	0.0009	0.003
Median:	0.0009	0.009
75%-tile:	0.001	0.02
Maximum:	0.002	0.03
Midrange:	0.001	0.02
Range:	0.001	0.03
Interquartile Range:	7.87E-005	0.01
Median Abs. Deviation:	4.61E-005	0.007
Mean:	0.001	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0003	0.008
Variance:	7.12E-008	6.07E-005
Coef. of Variation:	0.27	0.68
Coef. of Skewness:	2.93	0.37
Root Mean Square:	0.001	0.01
Mean Square:	1.03E-006	0.0002

Complete Spatial Randomness

Lambda: 536080.66
Clark and Evans: 1.44
Skellam: 97.14

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

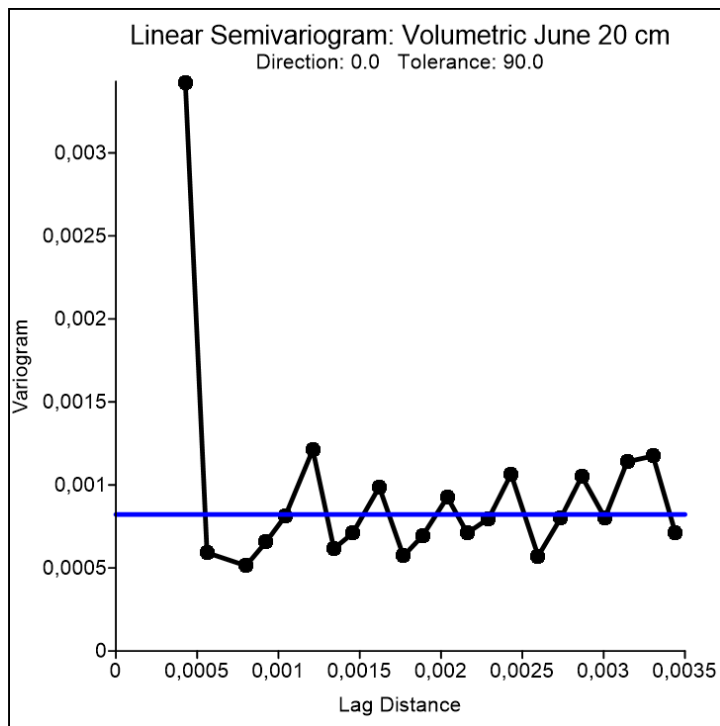


Figure 79: Linear Semi-variogram: Volumetric June 20 cm.

Variogram Grid Report: Volumetric June 20cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 59

Original Data: 59
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.003
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.04
75%-tile:	-26.97	26.84	0.06
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.062
Range:	0.007	0.008	0.12
Interquartile Range:	0.004	0.003	0.04
Median Abs. Deviation:	0.002	0.002	0.014
Mean:	-26.97	26.84	0.05
Trim Mean (10%):	-26.97	26.84	0.05
Standard Deviation:	0.002	0.002	0.03
Variance:	4.08E-006	4.47E-006	0.0008
Coef. of Variation:			0.6
Coef. of Skewness:			0.9

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.25	-0.6	9.38
Standard Deviation:	0.62	0.59	22.96

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0005	0.61
Residual:	56	0.05	0.0008	
Total:	58	0.05		

Coefficient of Multiple Determination (R^2): 0.02

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	5.58E-005
25%-tile:	0.0008	0.007
Median:	0.0009	0.012
75%-tile:	0.000987	0.034
Maximum:	0.001	0.1
Midrange:	0.0007	0.05
Range:	0.0006	0.1
Interquartile Range:	9.65E-005	0.03
Median Abs. Deviation:	4.33E-005	0.01
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.026
Variance:	1.34E-008	0.0007
Coef. of Variation:	0.14	1.06
Coef. of Skewness:	-2.15	1.3
Root Mean Square:	0.0009	0.04
Mean Square:	7.41E-007	0.0012

Complete Spatial Randomness

Lambda: 1017498.1
Clark and Evans: 1.72
Skellam: 279.56

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

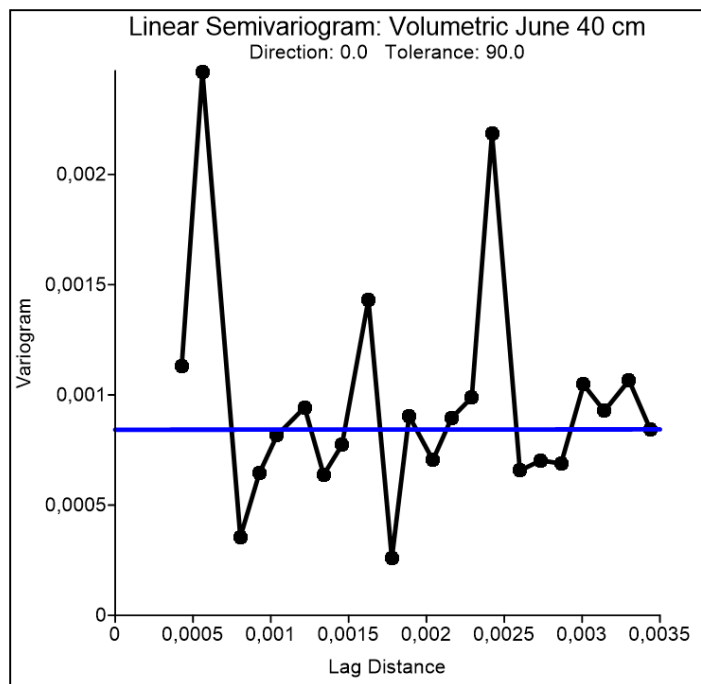


Figure 80: Linear Semi-variogram: Volumetric June 40 cm.

Variogram Grid Report: Volumetric June 40 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 54
Original Data: 54
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.01
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.05
75%-tile:	-26.97	26.84	0.07
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.008	0.12
Interquartile Range:	0.003	0.003	0.04
Median Abs. Deviation:	0.0018	0.002	0.019
Mean:	-26.97	26.84	0.05
Trim Mean (10%):	-26.97	26.84	0.05
Standard Deviation:	0.002	0.002	0.03
Variance:	3.698E-006	4.39E-006	0.0009
Coef. of Variation:			0.55
Coef. of Skewness:			0.86

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-6.7	-6.25	-13.08
Standard Deviation:	2.1	1.93	76.53

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.01	0.007	10.34
Residual:	51	0.03	0.0006	
Total:	53	0.05		

Coefficient of Multiple Determination (R^2): 0.29

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0003
25%-tile:	0.0008	0.008
Median:	0.0009	0.02
75%-tile:	0.0009	0.04
Maximum:	0.001	0.1
Midrange:	0.0007	0.05
Range:	0.0006	0.1
Interquartile Range:	0.0001	0.03
Median Abs. Deviation:	4.63E-005	0.01
Mean:	0.0009	0.03
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	0.0001	0.02
Variance:	1.48E-008	0.0005
Coef. of Variation:	0.14	0.92
Coef. of Skewness:	-2.04	1.1
Root Mean Square:	0.0009	0.03
Mean Square:	7.47E-007	0.001

Complete Spatial Randomness

Lambda: 931269.44
Clark and Evans: 1.65
Skellam: 236.54

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

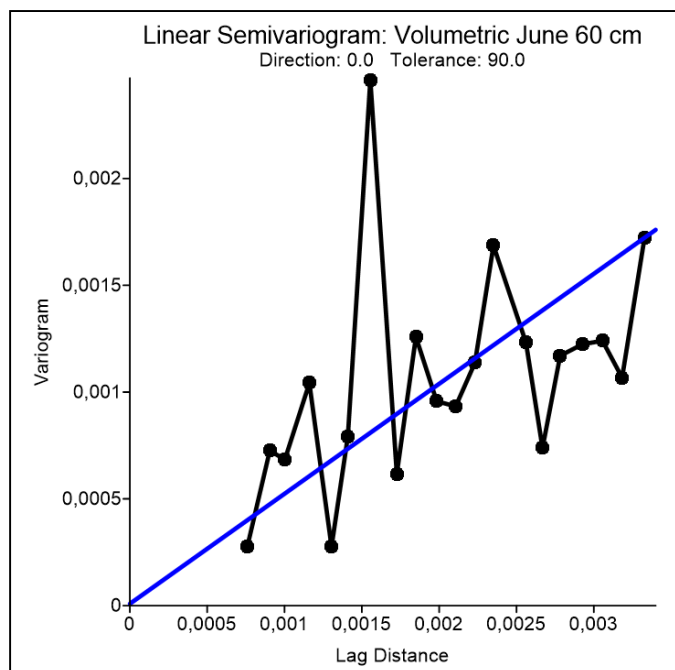


Figure 81: Linear Semi-variogram: Volumetric June 60 cm.

Variogram Grid Report: Volumetric June 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 44
Original Data: 44
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.01
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.06
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.007	0.12
Interquartile Range:	0.003	0.003	0.04
Median Abs. Deviation:	0.001	0.002	0.02
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.84	0.06
Standard Deviation:	0.002	0.002	0.03
Variance:	3.57E-006	3.98E-006	0.001
Coef. of Variation:			0.51
Coef. of Skewness:			0.5

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-2.65	-1.86	-21.4
Standard Deviation:	1.65	1.56	57

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.004	0.002	1.79
Residual:	41	0.04	0.001	
Total:	43	0.04		

Coefficient of Multiple Determination (R^2): 0.08

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	0.0001
25%-tile:	0.0008	0.01
Median:	0.0009	0.02
75%-tile:	0.0009	0.04
Maximum:	0.001	0.09
Midrange:	0.0009	0.05
Range:	0.0003	0.09
Interquartile Range:	9.46E-005	0.02
Median Abs. Deviation:	2.9E-005	0.01
Mean:	0.0009	0.03
Trim Mean (10%):	0.0009	0.02
Standard Deviation:	6.45E-005	0.02
Variance:	4.16E-009	0.0005
Coef. of Variation:	0.07	0.82
Coef. of Skewness:	-0.78	1.32
Root Mean Square:	0.0009	0.04
Mean Square:	8.009E-007	0.001

Complete Spatial Randomness

Lambda: 842412.47
Clark and Evans: 1.64
Skellam: 186.51

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

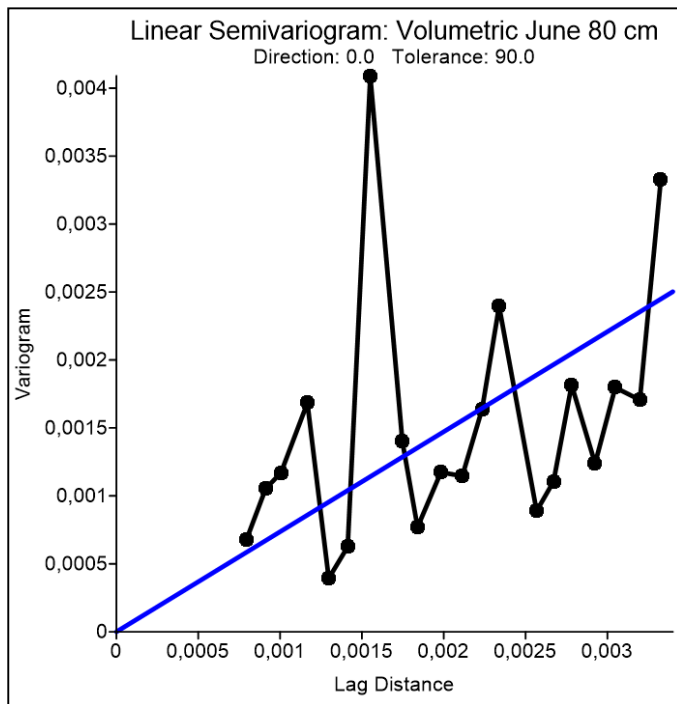


Figure 82: Linear Semi-variogram: Volumetric June 80 cm.

Variogram Grid Report: Volumetric June 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 35
Original Data: 35
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.02
25%-tile:	-26.97	26.84	0.05
Median:	-26.97	26.84	0.07
75%-tile:	-26.975	26.84	0.1
Maximum:	-26.97	26.84	0.17
Midrange:	-26.97	26.84	0.1
Range:	0.007	0.007	0.15
Interquartile Range:	0.003	0.003	0.05
Median Abs. Deviation:	0.002	0.002	0.03
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.07
Standard Deviation:	0.002	0.0026	0.04
Variance:	3.793E-006	4.15E-006	0.001
Coef. of Variation:			0.48
Coef. of Skewness:			0.66

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	9.64	6.99	72.44
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.02	-0.008	-3.8
Residual:	32	0.06	0.002	
Total:	34	0.05		

Coefficient of Multiple Determination (R^2): -0.31

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.004
25%-tile:	0.0009	0.02
Median:	0.0009	0.03
75%-tile:	0.0009	0.06
Maximum:	0.002	0.13
Midrange:	0.001	0.07
Range:	0.001	0.13
Interquartile Range:	4.21E-005	0.04
Median Abs. Deviation:	2.46E-005	0.019
Mean:	0.0009	0.04
Trim Mean (10%):	0.0009	0.036
Standard Deviation:	0.00023	0.03
Variance:	3.62E-008	0.001
Coef. of Variation:	0.2	0.817
Coef. of Skewness:	4.69	1.22
Root Mean Square:	0.001	0.05
Mean Square:	9.33E-007	0.003

Complete Spatial Randomness

Lambda: 670100.83
Clark and Evans: 1.55
Skellam: 137.49

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

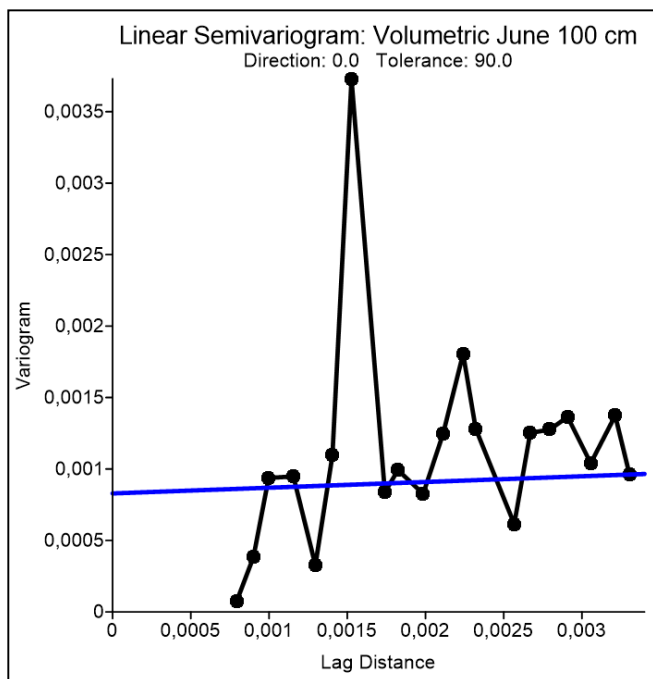


Figure 83: Linear Semi-variogram: Volumetric June 100 cm.

Variogram Grid Report: Volumetric June 100 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 28
Original Data: 28
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.02
25%-tile:	-26.97	26.84	0.06
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.11
Maximum:	-26.97	26.84	0.15
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.13
Interquartile Range:	0.003	0.0039	0.06
Median Abs. Deviation:	0.001	0.002	0.03
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.0029	0.002	0.03
Variance:	4.16E-006	4.4E-006	0.001
Coef. of Variation:			0.42
Coef. of Skewness:			0.19

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.93	-0.45	-12.96
Standard Deviation:	1.08	1.05	35.53

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0005	0.4
Residual:	25	0.03	0.00134	
Total:	27	0.03		

Coefficient of Multiple Determination (R^2): 0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.003
25%-tile:	0.0009	0.02
Median:	0.0009	0.03
75%-tile:	0.001	0.04
Maximum:	0.002	0.07
Midrange:	0.001	0.04
Range:	0.001	0.07
Interquartile Range:	7.87E-005	0.02
Median Abs. Deviation:	4.61E-005	0.01
Mean:	0.001	0.03
Trim Mean (10%):	0.00098	0.03
Standard Deviation:	0.0003	0.02
Variance:	7.12E-008	0.0003
Coef. of Variation:	0.27	0.61
Coef. of Skewness:	2.93	0.69
Root Mean Square:	0.001	0.034
Mean Square:	1.03E-006	0.001

Complete Spatial Randomness

Lambda: 536080.66
Clark and Evans: 1.44
Skellam: 97.14

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

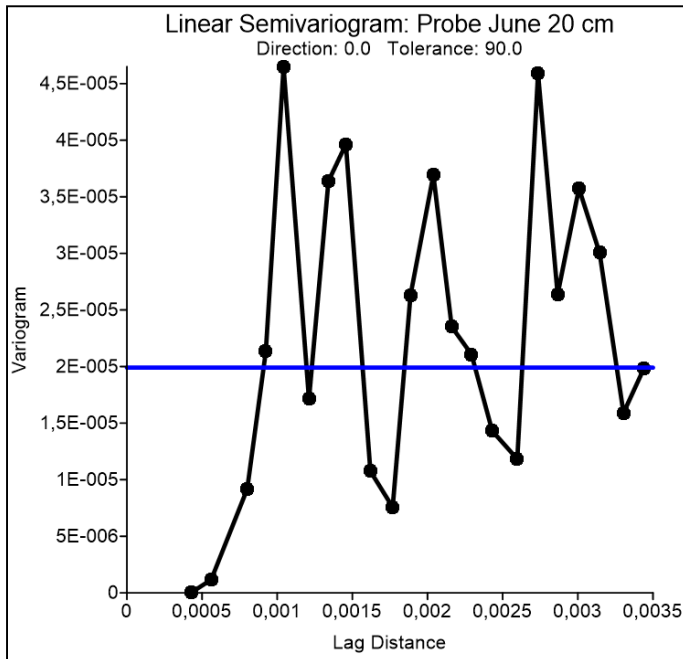


Figure 84: Linear Semi-variogram: Neutron probe June 20 cm.

Variogram Grid Report: Neutron probe June 20 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 59
Original Data: 59
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.03
75%-tile:	-26.97	26.84	0.03
Maximum:	-26.97	26.84	0.07
Midrange:	-26.97	26.84	0.05
Range:	0.007	0.008	0.04
Interquartile Range:	0.004	0.003	0.003
Median Abs. Deviation:	0.002	0.002	0.001
Mean:	-26.97	26.84	0.03
Trim Mean (10%):	-26.97	26.84	0.03
Standard Deviation:	0.002	0.002	0.006
Variance:	4.08E-006	4.47E-006	3.29E-005
Coef. of Variation:			0.18
Coef. of Skewness:			3.67

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	0.07	-0.09	4.35
Standard Deviation	0.12	0.12	4.56

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	3.07E-005	1.54E-005	0.46
Residual:	56	0.002	3.35E-005	
Total:	58	0.002		

Coefficient of Multiple Determination (R^2): 0.02

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0
25%-tile:	0.0008	0.0008
Median:	0.0009	0.002
75%-tile:	0.0009	0.003
Maximum:	0.001	0.03
Midrange:	0.0007	0.01
Range:	0.0006	0.03
Interquartile Range:	9.65E-005	0.002
Median Abs. Deviation:	4.33E-005	0.001
Mean:	0.0009	0.004
Trim Mean (10%):	0.0009	0.003
Standard Deviation:	0.0001	0.006
Variance:	1.34E-008	3.79E-005
Coef. of Variation:	0.136	1.62
Coef. of Skewness:	-2.15	2.96
Root Mean Square:	0.0009	0.007
Mean Square:	7.41E-007	5.18E-005

Complete Spatial Randomness

Lambda: 1017498.1
Clark and Evans: 1.72
Skellam: 279.56

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

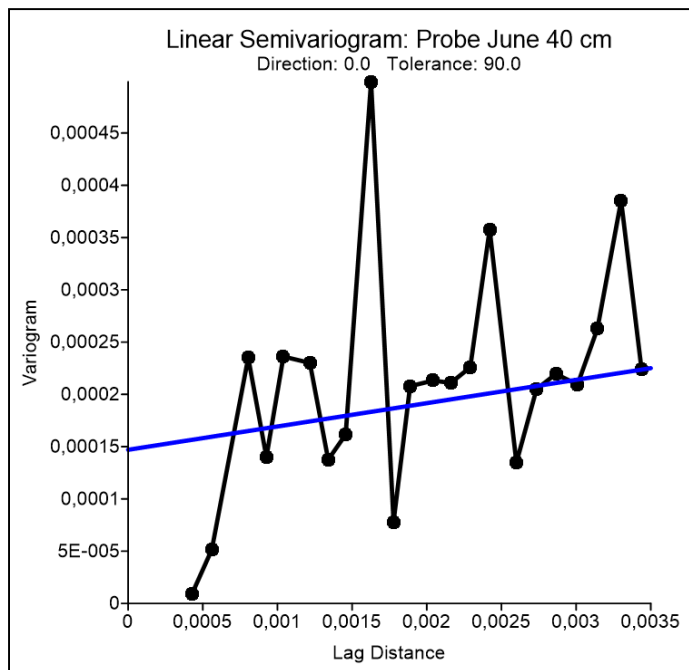


Figure 85: Linear Semi-variogram: Neutron probe June 40 cm.

Variogram Grid Report: Neutron probe June 40 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 54
Original Data: 54
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.04
25%-tile:	-26.97	26.84	0.04
Median:	-26.97	26.84	0.05
75%-tile:	-26.97	26.84	0.06
Maximum:	-26.97	26.84	0.1
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.008	0.06
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.84	0.05
Standard Deviation:	0.002	0.002	0.014
Variance:	3.7E-006	4.39E-006	0.0002
Coef. of Variation:			0.25
Coef. of Skewness:			1.05

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.91	-3.18	33.93
Standard Deviation:	1.06	0.97	38.64

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.002	0.001	6.94
Residual:	51	0.008	0.0002	
Total:	53	0.01		

Coefficient of Multiple Determination (R^2): 0.21

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0001
25%-tile:	0.0008	0.003
Median:	0.0009	0.007
75%-tile:	0.0009	0.017
Maximum:	0.0014	0.048
Midrange:	0.0007	0.02
Range:	0.00058	0.05
Interquartile Range:	0.0001	0.013
Median Abs. Deviation:	4.63E-005	0.005
Mean:	0.0009	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0001	0.012
Variance:	1.485E-008	0.0001
Coef. of Variation:	0.14	1.05
Coef. of Skewness:	-2.04	1.52
Root Mean Square:	0.0009	0.02
Mean Square:	7.49E-007	0.0003

Complete Spatial Randomness

Lambda: 931269.44
Clark and Evans: 1.65
Skellam: 236.54

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

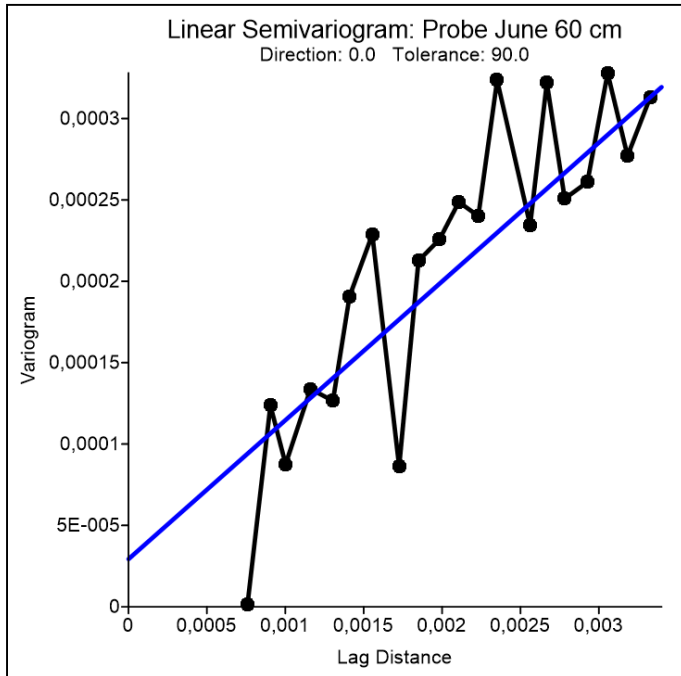


Figure 86: Linear Semi-variogram: Neutron probe June 60 cm.

Variogram Grid Report: Neutron probe June 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 44
Original Data: 44
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.05
25%-tile:	-26.97	26.84	0.06
Median:	-26.97	26.84	0.07
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.11
Midrange:	-26.97	26.84	0.08
Range:	0.0078	0.007	0.06
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.07
Trim Mean (10%):	-26.972	26.84	0.07
Standard Deviation:	0.002	0.002	0.02
Variance:	3.57E-006	3.98E-006	0.0002
Coef. of Variation:			0.21
Coef. of Skewness:			0.51

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-1.47	-1.41	-1.69
Standard Deviation:	0.79	0.75	27.33

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.001	0.0007	3.13
Residual:	41	0.009	0.00029	
Total:	43	0.01		

Coefficient of Multiple Determination (R^2): 0.13

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	4.0E-005
25%-tile:	0.0008	0.002
Median:	0.0009	0.009
75%-tile:	0.0009	0.01
Maximum:	0.001	0.04
Midrange:	0.0009	0.02
Range:	0.0003	0.04
Interquartile Range:	9.46E-005	0.01
Median Abs. Deviation:	2.9E-005	0.007
Mean:	0.0009	0.01
Trim Mean (10%):	0.0009	0.009
Standard Deviation:	6.45E-005	0.009
Variance:	4.16E-009	8.5E-005
Coef. of Variation:	0.07	0.92
Coef. of Skewness:	-0.78	1.14
Root Mean Square:	0.0009	0.014
Mean Square:	8.009E-007	0.0002

Complete Spatial Randomness

Lambda: 842412.47
Clark and Evans: 1.64
Skellam: 186.51

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

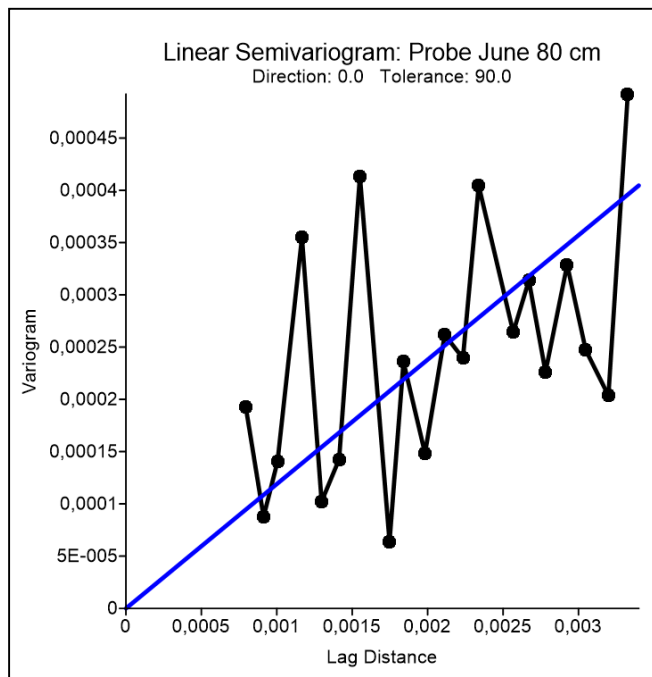


Figure 87: Linear Semi-variogram: Neutron probe June 80 cm.

Variogram Grid Report: Neutron probe June 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 35
Original Data: 35
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.06
25%-tile:	-26.97	26.84	0.08
Median:	-26.97	26.84	0.09
75%-tile:	-26.97	26.84	0.1
Maximum:	-26.97	26.84	0.12
Midrange:	-26.97	26.84	0.09
Range:	0.007	0.007	0.06
Interquartile Range:	0.003	0.003	0.03
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.09
Trim Mean (10%):	-26.97	26.84	0.09
Standard Deviation:	0.0012	0.002	0.02
Variance:	3.79E-006	4.15E-006	0.0003
Coef. of Variation:			0.18
Coef. of Skewness:			0.14

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	4.16	3.96	6.02
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.004	-0.002	-4.58
Residual:	32	0.01	0.00034	
Total:	34	0.009		

Coefficient of Multiple Determination (R^2): -0.40

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.0003
25%-tile:	0.0009	0.002
Median:	0.0009	0.01
75%-tile:	0.0009	0.02
Maximum:	0.0012	0.03
Midrange:	0.001	0.02
Range:	0.001	0.03
Interquartile Range:	4.21E-005	0.02
Median Abs. Deviation:	2.46E-005	0.008
Mean:	0.0009	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0002	0.009
Variance:	3.62E-008	8.13E-005
Coef. of Variation:	0.2	0.78
Coef. of Skewness:	4.69	0.37
Root Mean Square:	0.001	0.01
Mean Square:	9.33E-007	0.0002

Complete Spatial Randomness

Lambda: 670100.83
Clark and Evans: 1.55
Skellam: 137.49

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

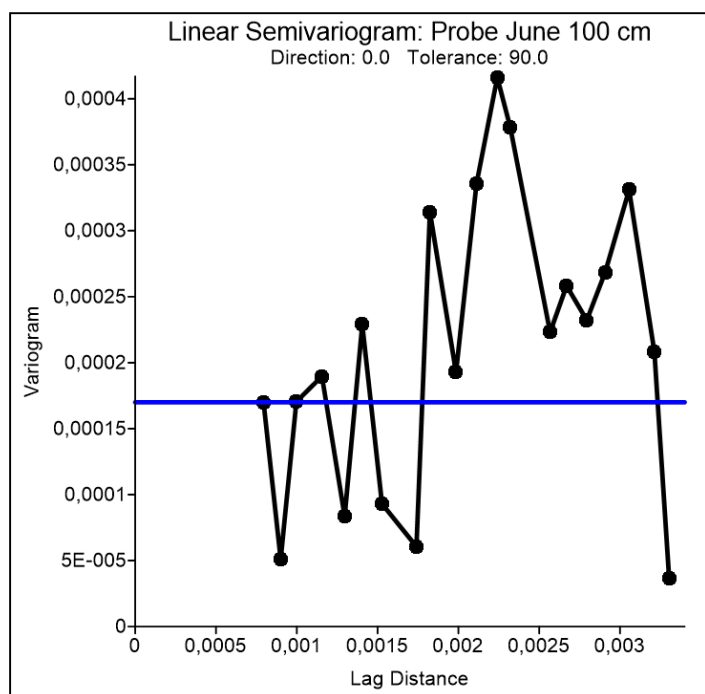


Figure 88: Linear Semi-variogram: Neutron probe June 100 cm.

Variogram Grid Report: Neutron probe June 100 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 28
Original Data: 28
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.07
25%-tile:	-26.97	26.84	0.09
Median:	-26.97	26.84	0.1
75%-tile:	-26.97	26.84	0.1
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.1
Range:	0.007	0.007	0.06
Interquartile Range:	0.003	0.004	0.02
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.1
Trim Mean (10%):	-26.97	26.84	0.09
Standard Deviation:	0.002	0.002	0.02
Variance:	4.16E-006	4.4E-006	0.0003
Coef. of Variation:			0.18
Coef. of Skewness:			0.05

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.44	-0.35	-2.44
Standard Deviation:	0.53	0.51	17.26

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0003	0.0001	0.47
Residual:	25	0.008	0.0003	
Total:	27	0.008		

Coefficient of Multiple Determination (R^2): 0.04

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.001
25%-tile:	0.0009	0.003
Median:	0.0009	0.01
75%-tile:	0.001	0.01
Maximum:	0.002	0.02
Midrange:	0.0014	0.01
Range:	0.0012	0.02
Interquartile Range:	7.87E-005	0.01
Median Abs. Deviation:	4.61E-005	0.007
Mean:	0.001	0.01
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0003	0.006
Variance:	7.12E-008	3.91E-005
Coef. of Variation:	0.27	0.63
Coef. of Skewness:	2.93	0.11
Root Mean Square:	0.001	0.01
Mean Square:	1.03E-006	0.0001

Complete Spatial Randomness

Lambda: 536080.66
Clark and Evans: 1.44
Skellam: 97.14

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

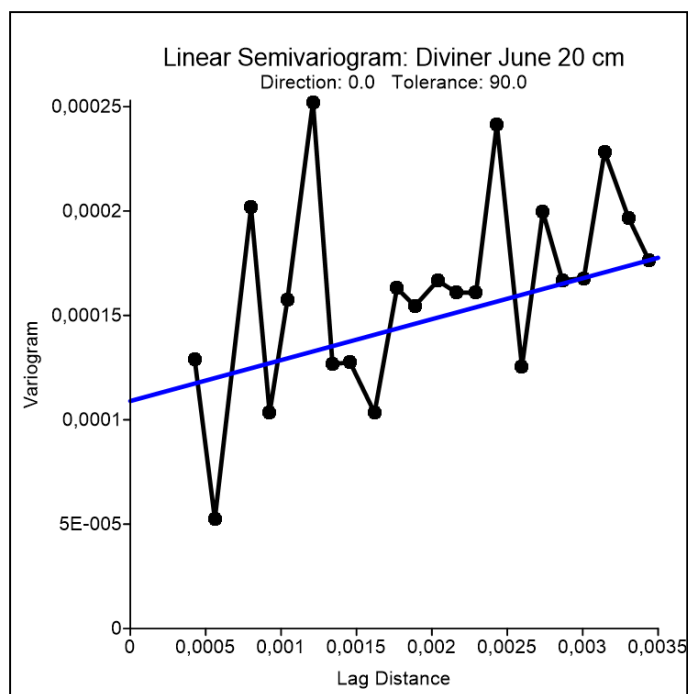


Figure 89: Linear Semi-variogram: Diviner June 20 cm.

Variogram Grid Report: Diviner June 20 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 59
Original Data: 59
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.008
25%-tile:	-26.97	26.84	0.03
Median:	-26.97	26.84	0.04
75%-tile:	-26.97	26.84	0.05
Maximum:	-26.967	26.84	0.07
Midrange:	-26.97	26.834	0.04
Range:	0.007	0.008	0.06
Interquartile Range:	0.004	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.009
Mean:	-26.97	26.84	0.04
Trim Mean (10%):	-26.97	26.84	0.04
Standard Deviation:	0.002	0.002	0.01
Variance:	4.08E-006	4.47E-006	0.0002
Coef. of Variation:			0.37
Coef. of Skewness:			0.31

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.23	-0.35	1.48
Standard Deviation:	0.3	0.29	11.37

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0005	0.0002	1.18
Residual:	56	0.01	0.0002	
Total:	58	0.01		

Coefficient of Multiple Determination (R^2): 0.04

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0002
25%-tile:	0.0008	0.006
Median:	0.0009	0.01
75%-tile:	0.0009	0.018
Maximum:	0.001	0.04
Midrange:	0.0007	0.02
Range:	0.0006	0.04
Interquartile Range:	9.65E-005	0.01
Median Abs. Deviation:	4.33E-005	0.01
Mean:	0.001	0.01
Trim Mean (10%):	0.001	0.01
Standard Deviation:	0.0001	0.01
Variance:	1.33E-008	0.0001
Coef. of Variation:	0.14	0.81
Coef. of Skewness:	-2.15	1.040
Root Mean Square:	0.0009	0.02
Mean Square:	7.41E-007	0.0003

Complete Spatial Randomness

Lambda: 1017498.1
Clark and Evans: 1.72
Skellam: 279.56

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

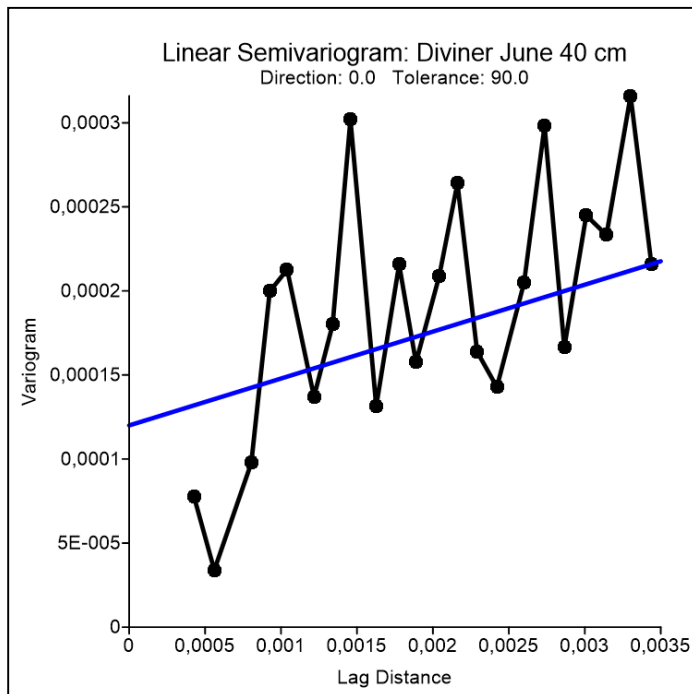


Figure 90: Linear Semi-variogram: Diviner June 40 cm.

Variogram Grid Report: Diviner June 40 cm

Variogram Grid

Maximum Lag Distance: 0.0035
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 54
Original Data: 54
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.02
25%-tile:	-26.97	26.84	0.05
Median:	-26.97	26.84	0.06
75%-tile:	-26.97	26.84	0.07
Maximum:	-26.97	26.84	0.1
Midrange:	-26.97	26.84	0.06
Range:	0.007	0.008	0.08
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.009
Mean:	-26.97	26.84	0.06
Trim Mean (10%):	-26.97	26.84	0.06
Standard Deviation:	0.002	0.002	0.02
Variance:	3.7E-006	4.39E-006	0.0003
Coef. of Variation:			0.26
Coef. of Skewness:			-0.08

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-3.3	-3.697	10.05
Standard Deviation:	1.16	1.06	42.19

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.004	0.002	10.11
Residual:	51	0.01	0.0002	
Total:	53	0.01		

Coefficient of Multiple Determination (R^2): 0.29

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0004	0.0003
25%-tile:	0.0008	0.005
Median:	0.00089	0.01
75%-tile:	0.0009	0.02
Maximum:	0.001	0.05
Midrange:	0.0007	0.02
Range:	0.0006	0.05
Interquartile Range:	0.0001	0.02
Median Abs. Deviation:	4.63E-005	0.007
Mean:	0.0009	0.02
Trim Mean (10%):	0.0009	0.01
Standard Deviation:	0.0001	0.01
Variance:	1.48E-008	0.0002
Coef. of Variation:	0.14	0.83
Coef. of Skewness:	-2.042	0.93
Root Mean Square:	0.0009	0.019
Mean Square:	7.49E-007	0.0004

Complete Spatial Randomness

Lambda: 931269.44
Clark and Evans: 1.65
Skellam: 236.54

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

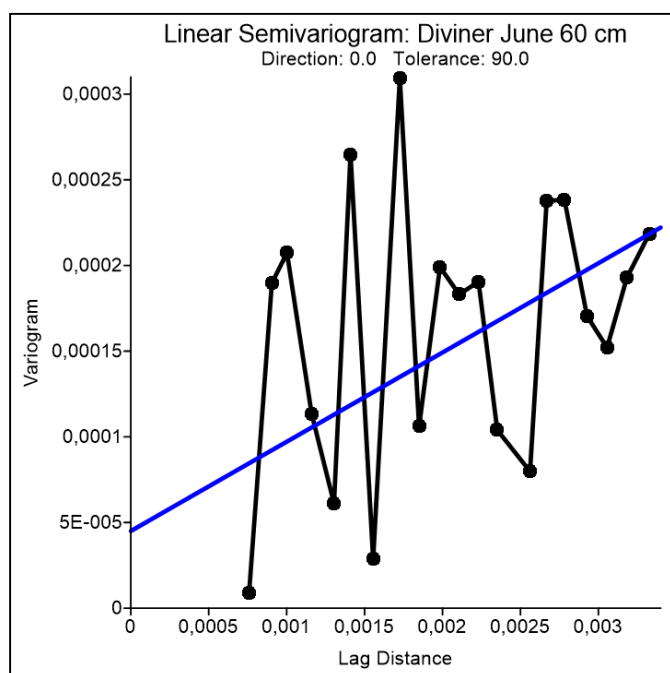


Figure 91: Linear Semi-variogram: Diviner June 60 cm.

Variogram Grid Report: Diviner June 60 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 44
Original Data: 44
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.07
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.11
Midrange:	-26.97	26.84	0.07
Range:	0.007	0.007	0.08
Interquartile Range:	0.003	0.003	0.02
Median Abs. Deviation:	0.001	0.002	0.007
Mean:	-26.97	26.84	0.07
Trim Mean (10%):	-26.974	26.84	0.07
Standard Deviation:	0.002	0.002	0.01
Variance:	3.57E-006	3.98E-006	0.0002
Coef. of Variation:			0.2
Coef. of Skewness:			-0.46

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.8	-0.87	0.9
Standard Deviation:	0.77	0.73	26.57

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0005	0.0002	1.16
Residual:	41	0.009	0.0002	
Total:	43	0.009		

Coefficient of Multiple Determination (R^2): 0.05

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0007	0.0008
25%-tile:	0.0008	0.005
Median:	0.0009	0.011
75%-tile:	0.0009	0.023
Maximum:	0.001	0.042
Midrange:	0.0009	0.02
Range:	0.0003	0.04
Interquartile Range:	9.467E-005	0.02
Median Abs. Deviation:	2.9E-005	0.006
Mean:	0.0009	0.015
Trim Mean (10%):	0.0009	0.014
Standard Deviation:	6.45E-005	0.011
Variance:	4.16E-009	0.0001
Coef. of Variation:	0.07	0.74
Coef. of Skewness:	-0.78	0.87
Root Mean Square:	0.0009	0.02
Mean Square:	8.009E-007	0.00045

Complete Spatial Randomness

Lambda: 842412.47
Clark and Evans: 1.64
Skellam: 186.51

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

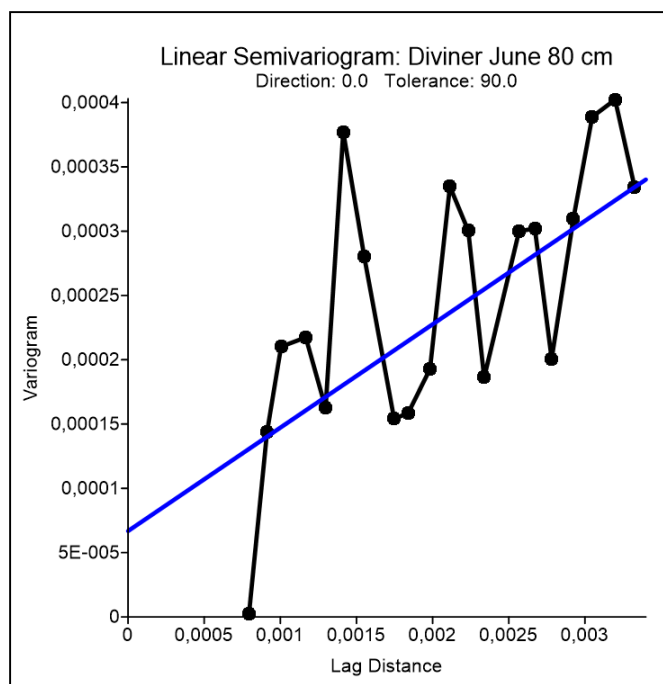


Figure 92: Linear Semi-variogram: Diviner June 80 cm.

Variogram Grid Report: Diviner June 80 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 35
Original Data: 35
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.02
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.08
75%-tile:	-26.97	26.84	0.09
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.1
Interquartile Range	0.002	0.003	0.02
Median Abs. Deviation:	0.002	0.002	0.01
Mean:	-26.97	26.84	0.08
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.002	0.002	0.02
Variance:	3.79E-006	4.15E-006	0.0004
Coef. of Variation:			0.23
Coef. of Skewness:			-0.03

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	4.47	4.41	2.23
Standard Deviation:	0	0	0

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	-0.004	-0.002	-4.08
Residual:	32	0.02	0.0005	
Total:	34	0.01		

Coefficient of Multiple Determination (R^2): -0.34

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.001
25%-tile:	0.0009	0.003
Median:	0.0009	0.006
75%-tile:	0.0009	0.02
Maximum:	0.002	0.05
Midrange:	0.001	0.02
Range:	0.001	0.05
Interquartile Range:	4.21E-005	0.01
Median Abs. Deviation:	2.46E-005	0.004
Mean:	0.0009	0.01
Trim Mean (10%):	0.00092	0.01
Standard Deviation:	0.0002	0.01
Variance:	3.62E-008	0.0001
Coef. of Variation:	0.2	0.1
Coef. of Skewness:	4.69	1.24
Root Mean Square:	0.0001	0.02
Mean Square:	9.33E-007	0.0003

Complete Spatial Randomness

Lambda: 670100.83
Clark and Evans: 1.55
Skellam: 137.49

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use

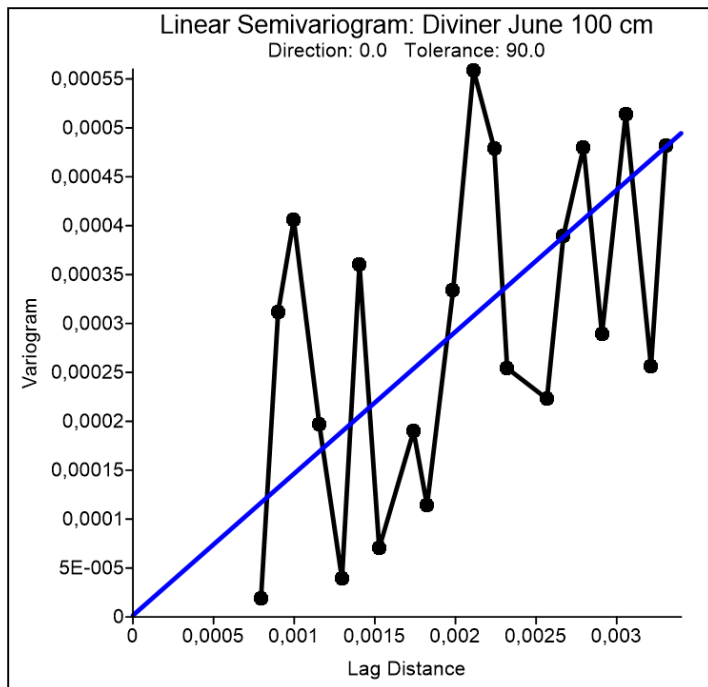


Figure 93: Linear Semi-variogram: Diviner June 100 cm.

Variogram Grid Report: Diviner June 100 cm

Variogram Grid

Maximum Lag Distance: 0.0034
Angular Divisions: 180
Radial Divisions: 100

Data Counts

Active Data: 28
Original Data: 28
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0

Univariate Statistics

	X	Y	Z
Minimum:	-26.97	26.84	0.03
25%-tile:	-26.97	26.84	0.07
Median:	-26.97	26.84	0.08
75%-tile:	-26.97	26.84	0.08
Maximum:	-26.97	26.84	0.13
Midrange:	-26.97	26.84	0.08
Range:	0.007	0.007	0.1
Interquartile Range:	0.003	0.004	0.02
Median Abs. Deviation:	0.001	0.002	0.01
Mean:	-26.97	26.84	0.09
Trim Mean (10%):	-26.97	26.84	0.08
Standard Deviation:	0.002	0.002	0.02
Variance:	4.16E-006	4.40E-006	0.0005
Coef. of Variation:			0.25
Coef. of Skewness:			-0.05

Planar Regression: $Z = AX + BY + C$ Fitted Parameters

	A	B	C
Parameter Value:	-0.47	-0.36	-3.002
Standard Deviation:	0.66	0.64	21.65

ANOVA Table

Source	df	Sum of Sqrs	Mean Sqr	F
Regression:	2	0.0003	0.0002	0.34
Residual:	25	0.01	0.0005	
Total:	27	0.01		

Coefficient of Multiple Determination (R^2): 0.03

Nearest Neighbor Statistics

	Separation	Delta Z
Minimum:	0.0008	0.003
25%-tile:	0.0009	0.006
Median:	0.0009	0.02
75%-tile:	0.001	0.03
Maximum:	0.002	0.05
Midrange:	0.001	0.026
Range:	0.001	0.046
Interquartile Range:	7.870E-005	0.019
Median Abs. Deviation:	4.61E-005	0.01
Mean:	0.001	0.02
Trim Mean (10%):	0.001	0.02
Standard Deviation:	0.0003	0.02
Variance:	7.12E-008	0.0003
Coef. of Variation:	0.27	0.81
Coef. of Skewness:	2.93	0.72
Root Mean Square:	0.001	0.03
Mean Square:	1.03E-006	0.0006

Complete Spatial Randomness

Lambda: 536080.66
Clark and Evans: 1.44
Skellam: 97.14

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: All
Duplicate filtering: Not In Use