SHORT-TERM SCIENTIFIC MISSION (STSM) FINAL REPORT

ON

EVALUATING HYDROLOGICAL CONTROLS ON THE MIGRATION OF METALLIC CONTAMINANTS IN URBAN SOIL

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Abstract

The short term scientific mission on the evaluation of hydrological controls on the migration of metallic contaminants in urban allotments and urban materials from locations, and mining sites in Portugal and Scotland. Using established soil-column leaching protocols, experiments were undertaken to understand metal leaching behaviour and release to groundwater produced interesting results migration rates of tracer species. Further assessment of the temporal variability or discharges of contaminant such as cadmium, zinc and copper for tracer studies was conducted. Parameter uncertainties were propagated in a numerical model CXTFIT for non-equilibrium conditions to understand the solute concentration and migration behaviour through a soil column. Leachate samples from the experiment at LNEC were sent to home institute (UWS) and are currently being analysed for tracer mobility (Ion chromatography and element concentration by ICPMS). Data will be fed into geochemical models (PHREEQC & GWB) to simulate surface transport and identify solubility limiting phases. Additional soil samples were collected for further analysis. Skills gained in the interpretation of hydrogeochemical data and modelling will be used to understand the impact of contaminated urban soil on food security. The visit established broader collaboration and to develop future studies.

Introduction

This report contains an overview of the short-term scientific mission (STSM) under COST Action TU1201 at National Laboratory for Civil Engineering (LNEC) Lisbon, Portugal from 14th October to 14th November, 2013. The STSM underpins COST Action working group (WG 3 “ecology”).

COST Action TU1201 urban allotment gardens (AG) in European cities Future, Challenges and Lessons Learned is co-sponsored by the COST European Cooperation in Science and Technology, European Science Foundation and ILS – Research institute for Regional and Urban Development and was launched to promote interest and development in allotment gardens through networking with researchers, students, policy makers and stakeholders in European countries (COST, 2013). It has impacted greatly on my research through undertaking the STSM and addressing a number of research questions for my PhD study.

Allotment gardens (AG) are increasingly expanding and meeting the needs of people wanting to grow their own food in European cities (eg., Scotland, Portugal). However, about 75% of AG are owned by the local authority in Scotland while in Portugal, a greater portion are privately owned (SAGS, 2007; CCMGS, 2013).

The aim of the STSM was to conduct tracer studies to model pollutant transport on contaminated urban soil / surface materials from urban locations in Portugal and Scotland using LNEC column leaching facility to generate lab data to compare to field observations. This will help understanding metal leaching and assessing temporal variability and release to groundwater impacting on urban allotment gardens.

The purpose of the study was to understand the impact of soils on hydrogeochemistry of groundwater through evaluating temporal discharges or release of contaminants such as copper, zinc and cadmium from soil materials in relation to the seasonal effects of near surface hydrology and data integrated with numerical and hydro-geochemical models (CXTFIT 2.0, PHREEQC 2.0 and Geochemist’s Workbench – GWB) to simulate for solute concentrations and speciation of water analysis to evaluate dissolution and precipitation of the tracers and identified minerals (Toride et al. 1995) (Parkhurst and Appelo, 1999) (Bethke and Yeakel, 2013). Also, based on previous and on-going studies at LNEC DHA allotment on soil and water contamination and impacts to the environment, experience of collection and analysis was gained. Additional sample was collected for follow up work on soil quality evaluation, soil-plant transfer and bioaccessibility assessments thereby building synergy and partnership with the host institute. Furthermore, skills on lab modelling and interpretation of hydrogeochemical data useful for understanding urban contaminated soil effect in food security were gained through the STSM.

For timely completion of the STSM, studies were divided into several tasks such as field and lab works that lasted for three weeks, interpretation of results & findings and report writing set for the fourth and final weeks (Fig. 1).

STSM SCHEDULE / WORK PLAN

ID	Task Name	Start	Finish	Duration
1	**Field & Lab work**	14-10-2013	05-11-2013	3w 2d
2	Soil collection & characterisation	14-10-2013	18-10-2013	1w
3	Equipment calibration (column leaching & meters)	21-10-2013	24-10-2013	4d
4	First Column experiment (tracer study) using ZnCl2 and reporting	25-10-2013	25-10-2013	1d
5	Second Column experiment (tracer study) using Cl2Cu.2H20	28-10-2013	30-10-2013	3d
6	Output samples sent for ICP analysis	31-10-2013	14-11-2013	2w 1d
7	Third Column experiment (leaching study)	31-10-2013	11-11-2013	1w 3d
8	Fourth / final Column experiment (leaching & tracer studies) using CdCl2	31-10-2013	11-11-2013	1w 3d
9	**Results & Interpretation**	05-11-2013	14-11-2013	1w 3d
10	Numerical modelling	05-11-2013	14-11-2013	1w 3d
11	Geochemical modelling	11-11-2013	14-11-2013	4d
12	Report writing	28-10-2013	14-11-2013	2w 4d

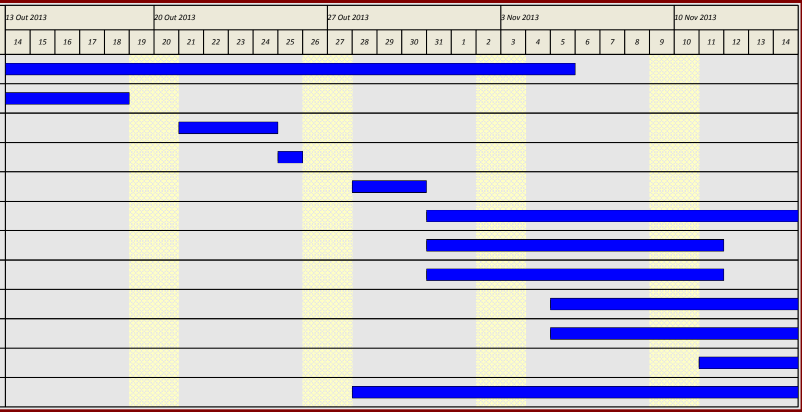

Fig. 1 Short term Scientific Mission Schedule

Methodology

Five different experiments were performed using three different urban materials from different origins and locations such as uncontaminated soil materials from LNEC campus (used for 2 tracer studies e.g., LNEC UA Zn and LNEC UA Cu), contaminated materials from historic mining site of human impact (leaching & tracer studies e.g., UWS LH/W and UWS LH/W Cd) and contaminated soils from a typical bulk site previously analysed for possible pollutants (leaching / waste characterisation e.g., UWS US) (Markiewicz-Patkowska etal. 2005). Both contaminated materials are of Scottish origin while the uncontaminated one is from Portugal.

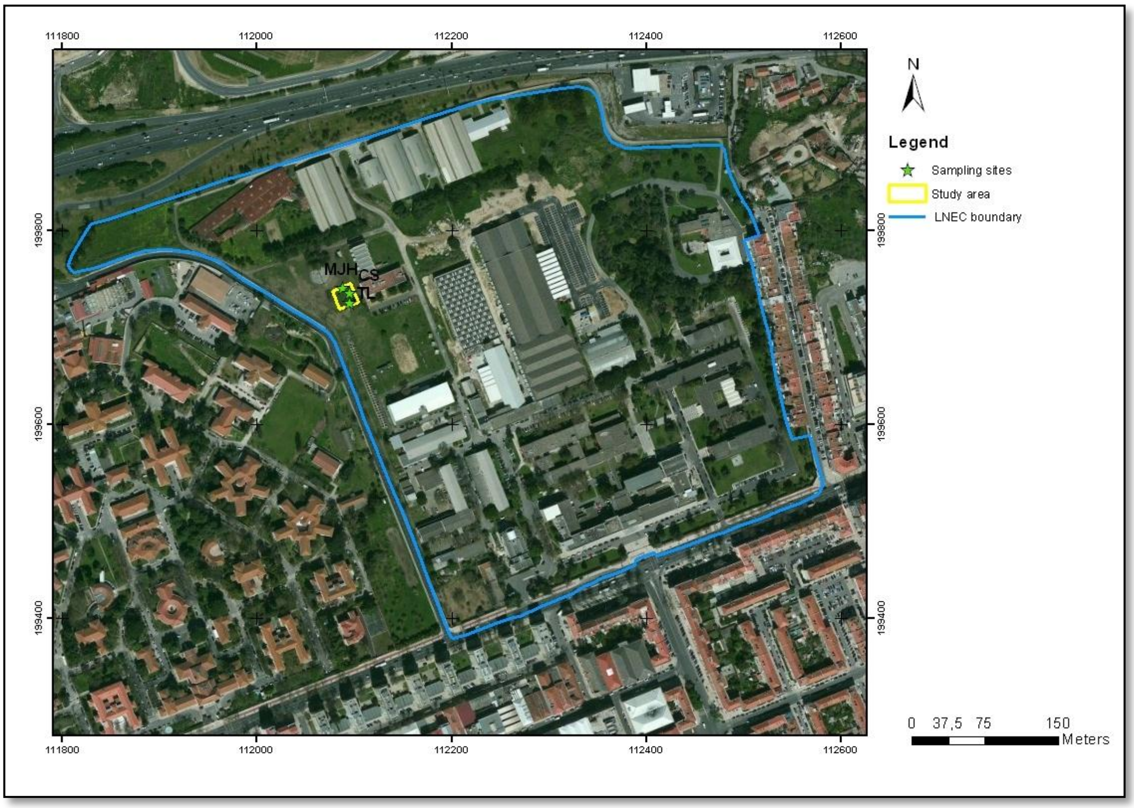

Fig. 2a Location of LNEC Campus & Allotment gardens

The allotment garden soils used for the study in Portugal is located at LNEC campus (about 400m^{2}in size), containing approximately 16 allotment plots (Fig. 2a & b). Soil materials from DHA urban allotment gardens were collected from intervals and depths (0-20, 20-40cm) from the discrete sampling campaign and characterized before the tracer studies (Appendix 1). The geographical points of soil collection were measured and recorded using hand held GPS (GARMIN series).

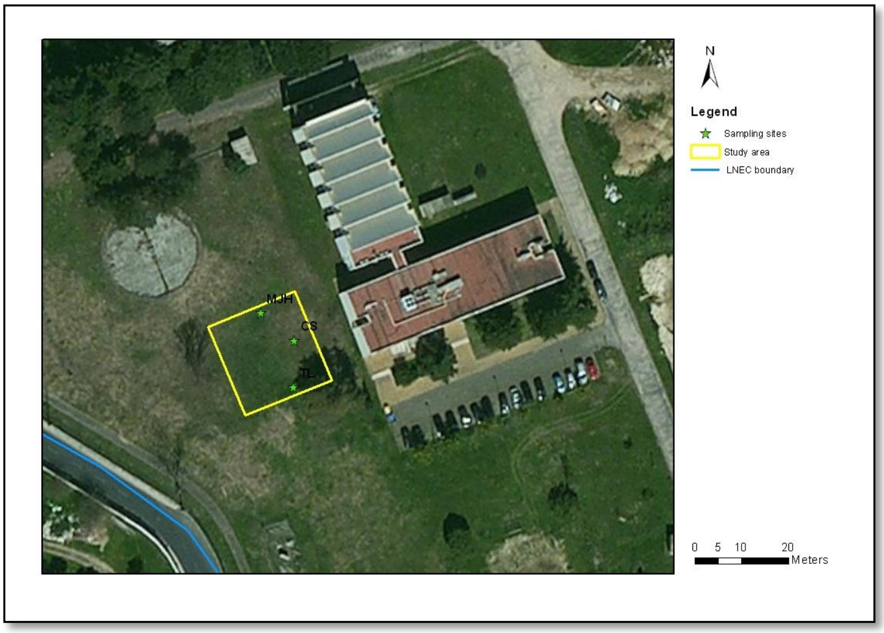

Fig. 2b LNEC DHA Allotment gardens with study plots enclosed in Yellow Square

They were labelled and stored in plastic bags before transported to the laboratory for experimental work. A greater portion of the soil materials were dried for 48hrs and sieved through 2mm mesh (some additional samples collected for further study at home institute).

The experimental work was divided into two sections e.g., soil characterization and tracer leaching studies.

Soil Characterization:

About 100gram of collected soil materials (un-dried) were used to determine the humidity of the soil. The weight of the un-dried samples were recorded, dried afterwards for 48hrs and calculated for the amount of water contained in the soil.

In addition, the soil bulk density and porosity of the soil materials were determined by saturating dried materials (200 gram) in cups for 24hrs (Appendix 2). The dried and saturated weights were measured with the volume of water in soil materials calculated. Based on the obtained results, the soil-column was further calibrated.

The granulometry as determined from the soil materials and this was done to measure their grain size distribution. However, in order to separate the clays from sand grains, about 100gram of dried sample was washed through 63μm sieve and samples dried for 48hrs at 40^0C and then weighed again before using an automatic sieve shaker (twelve standard sieves) with reference (ASTM D6913) to collect and separate grains (shake for 10mins at 30mm amplitude). Retained grains in each sieve were measured and results plotted to show the distributions of grains. Apart from the grain or particle size distribution, the soil materials were also assessed with finger method and further mineralogy description (Appendix 2).

Furthermore, organic matter contained in each soil layer was calculated for loss of ignition. Some portions of air-dried soil materials were collected in crucible and calculate for ignition loss. Materials were further oven dried at

550 F for 16hrs and cooled in desiccators afterwards before weighing. Duplicate measurements were made at intervals.

An acid test was done on the materials using Hydrochloric acid (HCl). About 2 gram of soil was measured in glassware dish and drops of HCl added to the portion. Bubbles indicate the presence of carbonate.

Tracer studies:

Before the tracer experiment, the empty column (30cm height, 5cm diameter) was properly acid cleaned to prevent contamination and then weighed. Dried soil materials were packed in the column with reference to the Technical specification under "Characterization of waste - Leaching behaviour tests - Up-flow percolation test (under specific conditions)" (CEN/TS 14405:2004) and weight of soil materials and column recorded before saturation (with distilled water) (Appendix 2). The sample was weighed after 24hrs saturation and the room temperature recorded on lab / test report. The porosity and apparent density was determined from measured values. Distilled water was pumped through the soil-column and output samples collect per volume over time and calculated for the flow rate. Proper quality assurance and control was taken during the whole assay.

A tracer study was conducted using 80ml $CuCl_2$, $ZnCl_2$ and $CdCl_2$ tracers in separate experiments. About 50ml tracer was used for the analysis (and other portion sent together with aliquots) and output samples collected at intervals through 0.63 μm filter fit at the bottom of column into 10ml tubes and depends on the pore volume or flow rate could be either fast or slow lasting for 24hrs or more. After the last output collection was made, parameters such as pH, reduction-oxidation potential (Eh), electrical conductivity (EC) and volumes of samples was measured and separated into 30ml HDPE bottles. The output samples and tracer (about 30ml) were acidified (HNO_3) following standard methodology for water analysis by ICPMS (ASTM D5673 – 10) and collected for further metal analysis (quality control including analysis of water reference material ERM – CA011b) and together with soil materials used for the tracer study to home institute (UWS), UK (are shown in Appendix 5) and data will be integrated with hydro-geochemical models (PHREEQC & GWB) to understand the precipitation and dissolution of tracers in solution.

Hydraulic conductivity or permeability, Darcy's velocity and actual velocity or pore water velocity was calculated and used in numerical model (CXTFIT 2.0 in Excel 2007) to understand the solute concentration and transport in the material.

Soil materials from typical urban environment and historic industrial sites in Scotland were studied for leaching behaviour, pollutant transport, temporal discharge and release of contaminants and tracer mobility.

Other studies conducted involved extensive hydrological skills on routine monitoring for soil and water in the DHA allotment site and general laboratory reporting.

Results

The experimental results based on the soil characterisation and tracer leaching studies for LNEC UA are summarised as follows;

Humidity of the materials: The humidity of the LNEC urban allotment soils was calculated in percentage.

$$\textbf{Humidity}\ (\%) = \text{Humidity (g) / Dry soil porosity (g)} \times 100$$

A lower humidity (7.2%) was determined for material depth 0 – 20cm and higher (10.4%) for 20 – 40cm.

Porosity and bulk density: The porosity was determined in percent and density measured in g/cm^3.

$$\mathbf{n}\ (\%) = Vw\ (cm^3) / Vt\ (cm^3) \times 100$$

$$\boldsymbol{\rho b}\ (g/cm^3) = Wd\ (g) / Vt\ (cm^3)$$

Where;

n equals porosity, **Vw** equals the amount or volume of water in material or soil sample and

Vt equals the total volume of cup and soil.

ρb equals density and **Wd** equals the weight of dry soil.

The porosity for both LNEC UA soil layers was measured as 39.9% for 0 – 20cm and 39.4% for 20 – 40cm with the same density (1.5).

Organic matter content: The soil organic matter calculated for ignition loss is higher (about 1.7%) on the top soil 0 - 20 cm while lower value of 1.5% was determined on the bottom soil 20 - 40 cm.

Granulometry / Particle Size Distribution (PSD): The top material mainly contains sands and a few clay while the bottom soil consists of sands, a few gravel and silt & clays are shown in Table 1 (and appendix 3a & b).

Table 1 Granulometry / Particle Size Distribution (PSD) for LNEC Urban allotment soils

GRANULOMETRY / PARTICLE SIZE DISTRIBUTION (PSD)					
	Sieve ATSM D6913	**Mash Dimension (fi)**	**Diameter (mm)**	**Weight of sample 0 - 20cm**	**Weight of sample 20 - 40cm**
Gravel	5	-2	> 4	1.1651	3.5125
Gravel	7	-1.5	4 - 2.8	1.3512	1.1814
Gravel	10	-1	2.8 - 2	1.9323	1.2441
Coarse sand	14	-0.5	2 - 1.4	2.528	1.7311
Coarse sand	18	0	1.4 - 1	3.2513	1.9413
Coarse sand	25	0.5	1 - 0.71	5.3823	2.8866
Medium sand	35	1	0.71 - 0.5	7.1838	3.4922
Medium sand	45	1.5	0.5 - 0.355	8.5238	3.741
Medium sand	60	2	0.355 - 0.25	8.1445	5.6166
Fine sand	80	2.5	0.25 - 0.18	9.6872	7.8362
Fine sand	120	3	0.18 - 0.125	7.9194	8.2329
Fine sand	170	3.5	0.125 - 0.09	5.0349	7.0069
Sand	230	4	0.09 - 0.063	4.1667	5.8357
Silt & clay	Base		<0.063	0.0763	0.1199

Tracer studies: The tracer experiments for the LNEC UA Zn, LNEC UA Cu and UWS LH/W Cd revealed interesting results based on their transport and period of experiment (Appendix 4a, b & c). However, the typical bulk material from an urban site previously studied (reference) maintained high values of conductivity requiring the leaching process to be maintained.

Discussion

Measured results from the soil characterization of materials collected from LNEC campus shows the material contains about 30 percent of clays and a greater portion of sands. However, additional variety or sources of materials such as glass, scrap metals, bricks, charcoal and other type of organic matter and fossils were identified, which are likely contributed by human frequent interactions with soil (Appendix 2). A greater portion of organic matter is present on the top soil materials than the bottom (20 – 40cm) and both samples contain carbonate which is essential for organic produce but not in excess.

The tracer study using LNEC UA and UWS LH/W based on numerical modeling reveals the mobility and bioavailability of heavy metals such as copper, zinc and cadmium in soil environment and could be greatly controlled by sorption and desorption. This could be affected by the physical and chemical characteristics of soil. However, on-going chemical analysis is being carried out at UWS using the inductively coupled plasma mass spectrometry (ICP-MS) and will provide further details of the migration process. From the experiments carried out so far, it seems zinc is more mobile than copper with cadmium less mobile (Appendix 4a, b & c). The numerical model was used to calibrate the solute transport parameters, and to perform a sensitivity of velocity, dispersivity and tracer pulse duration influence on the convection dispersion equation (CDE) model prediction and Monte Carlo analysis (MIM) for the non-equilibrium scenario (Fig. 3). The dispersivity and porosity were propagated for uncertainty to predict uncertainty for breakthrough curves.

These results will be disseminated in peer reviewed journal articles and at conferences in the future. Full acknowledgement of the COST action support will be given.

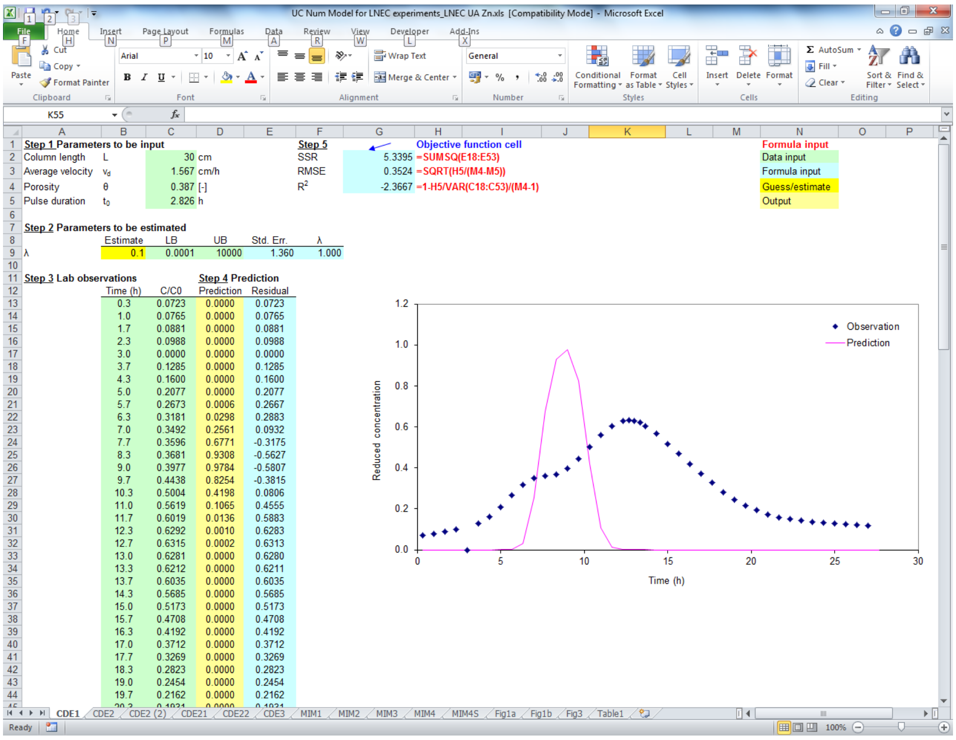

Fig. 3 CXTFIT Numerical modelling for Zinc (Zn) experiment (prediction done with convection dispersion model equation CDE and Monte Carlo analysis MIM)

Conclusion

The one month visit to the National Laboratory for Civil Engineering (LNEC) Lisbon, Portugal to model pollutant transport on contaminated urban soil / surface materials was a success with gain and motivation for collaboration for my broader study. It provided future collaboration for wider area of similar interest. Furthermore, additional data will be produced from the on-going chemical analysis at home institute which will integrate with hydro-geochemical models (PHREEQC, GWB) to simulate catchment surface transport and solubility limiting phases. This will help understanding the release and local groundwater temporal variability. The "typical" bulk urban soil is currently been leached at LNEC.

Acknowledgement

I am grateful to COST action TU1201 for providing me with an opportunity to establish this study and also my profound gratitude goes to both home and host supervisors Professor Andrew Hursthouse, Dr Simon Cuthbert and Dr Teresa Leitão, for their collaboration and extensive studies. I am also grateful to the senior technician at LNEC, Maria José Henriques for her assistance during the study.

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APPENDICES

Appendix 1

FIELD WORK: Sample collection at LNEC allotment garden







Soil materials collection (from 0 – 20cm and 20 – 40cm) for characterisation and leaching studies. Additional sample collection for follow up work on soil quality evaluation, soil-plant transfer and bioaccessibility assessments.

Appendix 2

LAB WORK: Soil Characterisation and Tracer studies

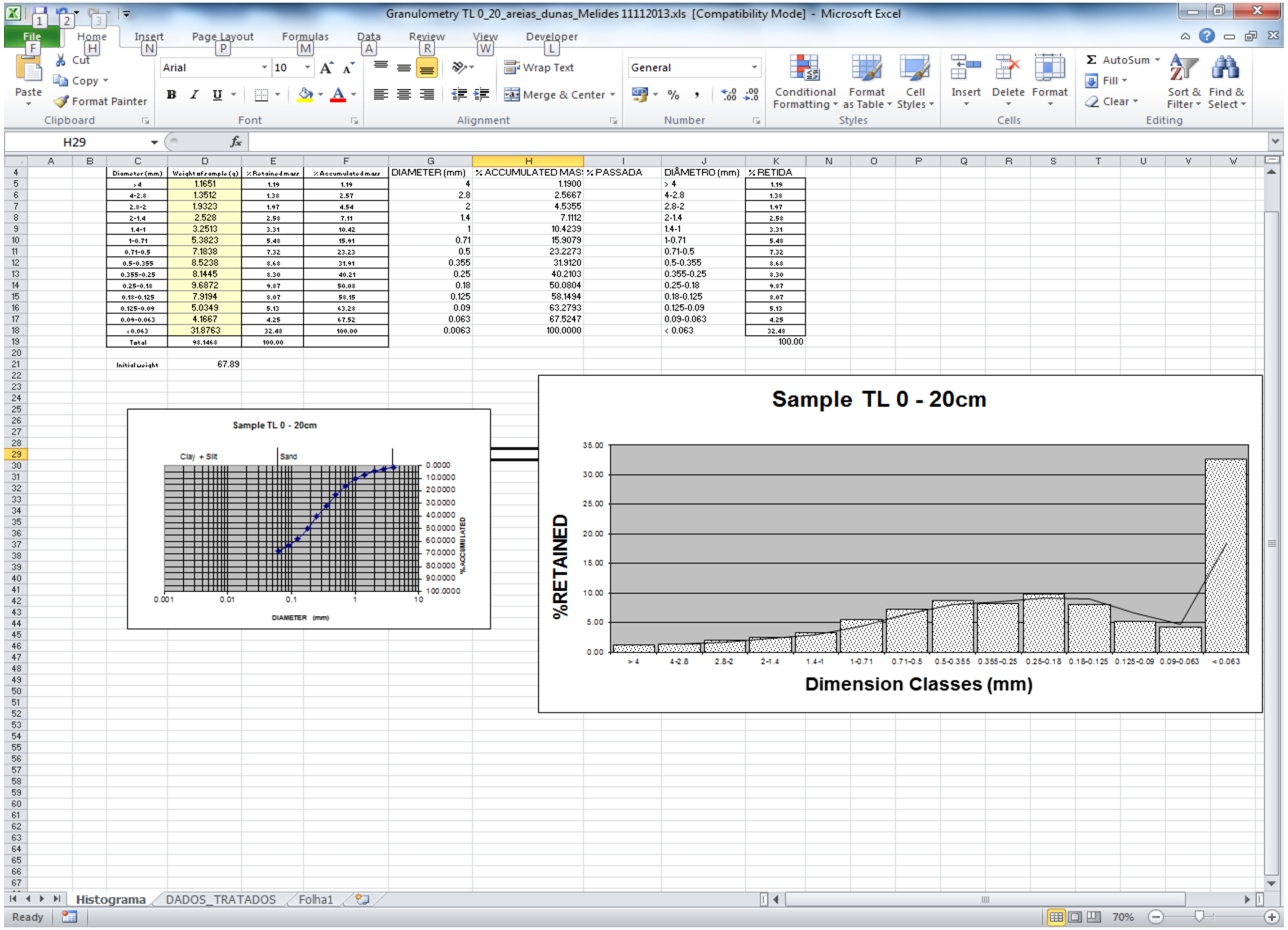
Characterisation of the materials for particle sieve distribution, porosity and apparent density and acid test, follow up packing of column for leaching experiment and column saturation.

Output sample collection in10ml tubes

Tracers

Multiparameter (pH, Eh, EC, DO, Temp)

Appendix 3a

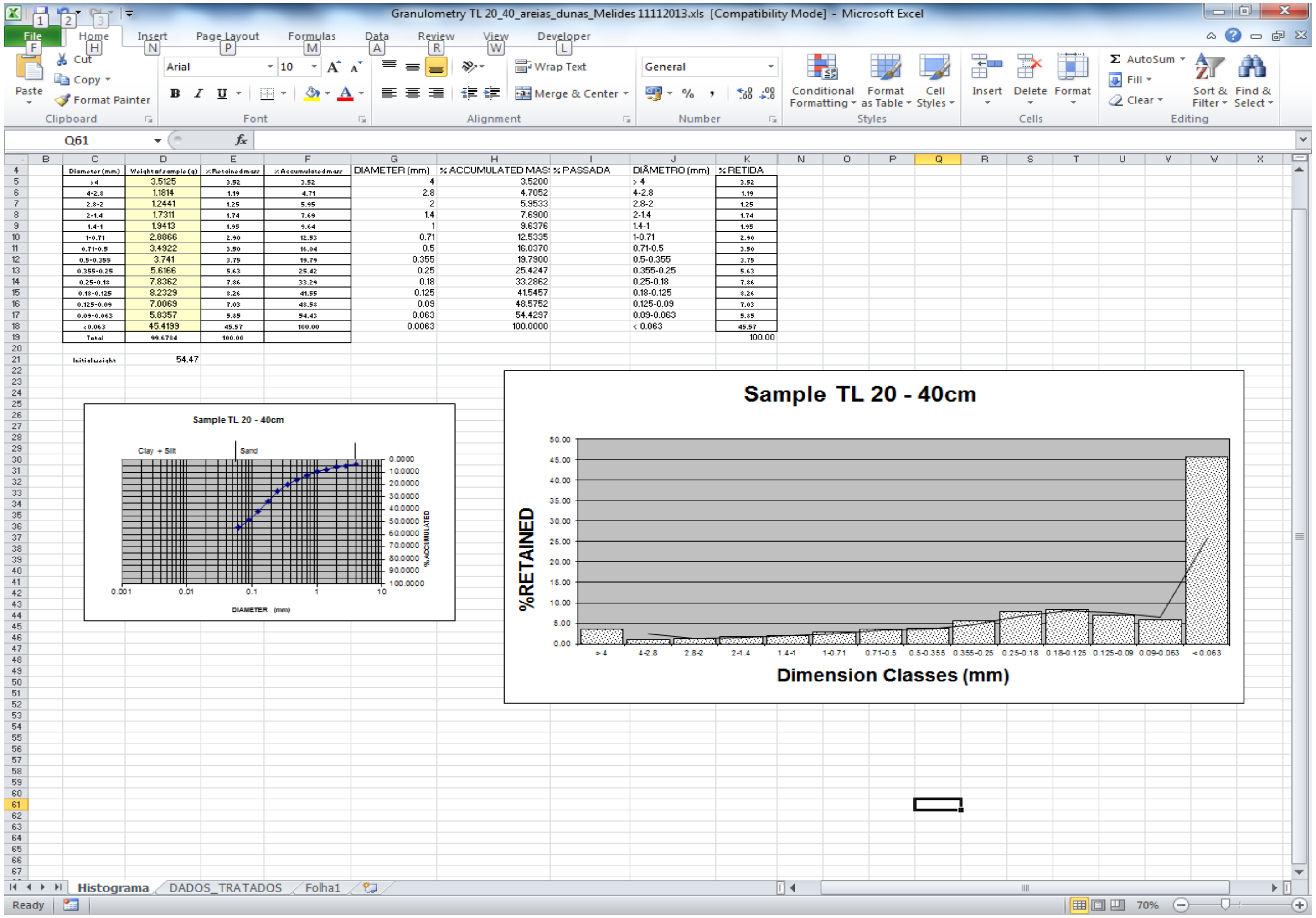


Diameter (mm)	Weight of sample (g)	% Retained mass	% Accumulated mass	DIAMETER (mm)	% ACCUMULATED MAS:	% PASSADA	DIÂMETRO (mm)	% RETIDA
>4	1.1651	1.19	1.19	4	1.1900		> 4	1.19
4-2.8	1.3512	1.38	2.57	2.8	2.5667		4-2.8	1.38
2.8-2	1.9323	1.97	4.54	2	4.5355		2.8-2	1.97
2-1.4	2.528	2.58	7.11	1.4	7.1112		2-1.4	2.58
1.4-1	3.2513	3.31	10.42	1	10.4239		1.4-1	3.31
1-0.71	5.3823	5.48	15.91	0.71	15.9079		1-0.71	5.48
0.71-0.5	7.1838	7.32	23.23	0.5	23.2273		0.71-0.5	7.32
0.5-0.355	8.5238	8.68	31.91	0.355	31.9120		0.5-0.355	8.68
0.355-0.25	8.1445	8.30	40.21	0.25	40.2103		0.355-0.25	8.30
0.25-0.18	9.6872	9.87	50.08	0.18	50.0804		0.25-0.18	9.87
0.18-0.125	7.9194	8.07	58.15	0.125	58.1494		0.18-0.125	8.07
0.125-0.09	5.0349	5.13	63.28	0.09	63.2793		0.125-0.09	5.13
0.09-0.063	4.1667	4.25	67.52	0.063	67.5247		0.09-0.063	4.25
<0.063	31.8763	32.48	100.00	0.0063	100.0000		< 0.063	32.48
Total	98.1468	100.00						100.00

Initial weight 67.89

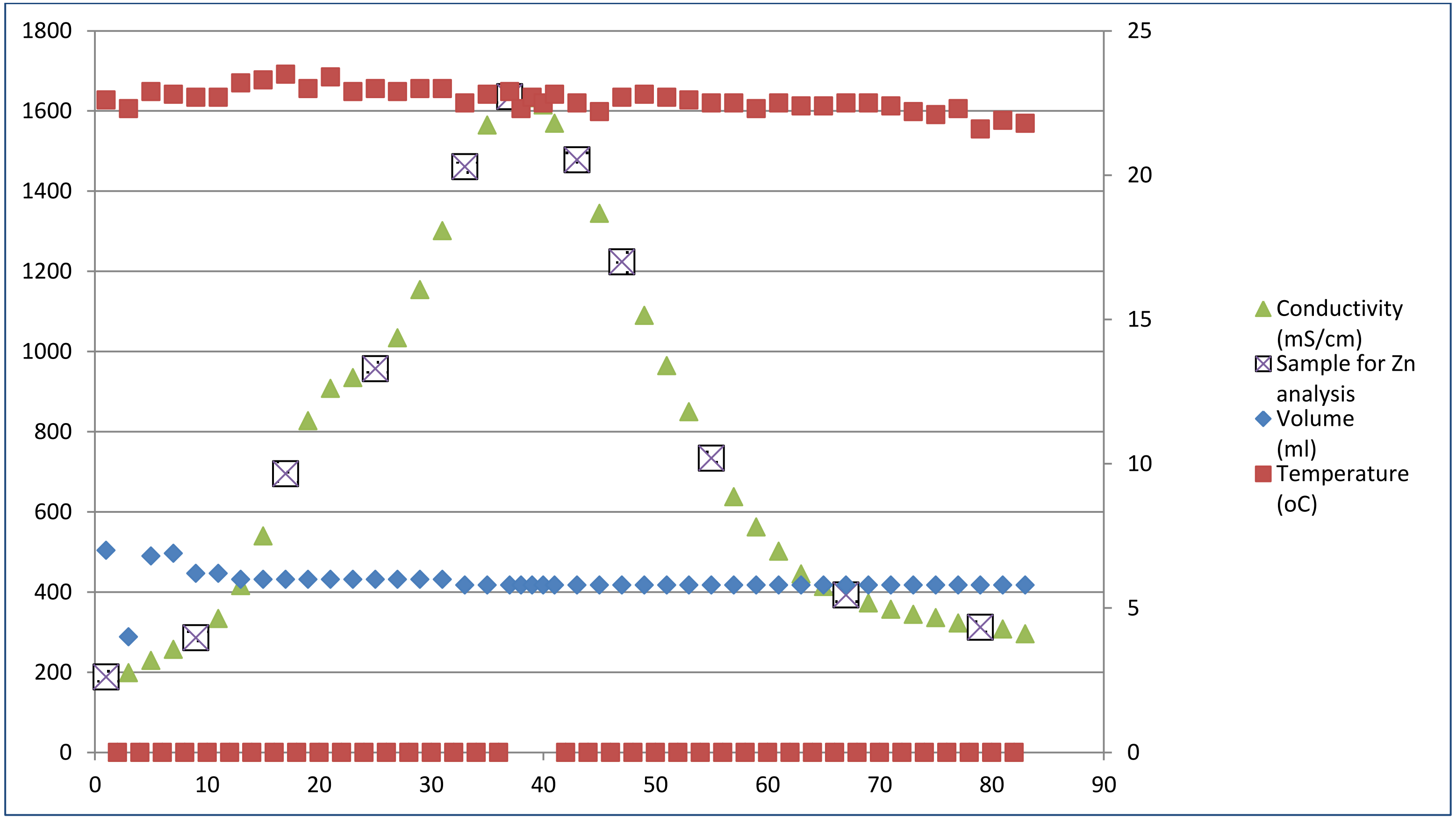
Particle Size Distribution for top soil material (TL 0 – 20cm)

Appendix 3b



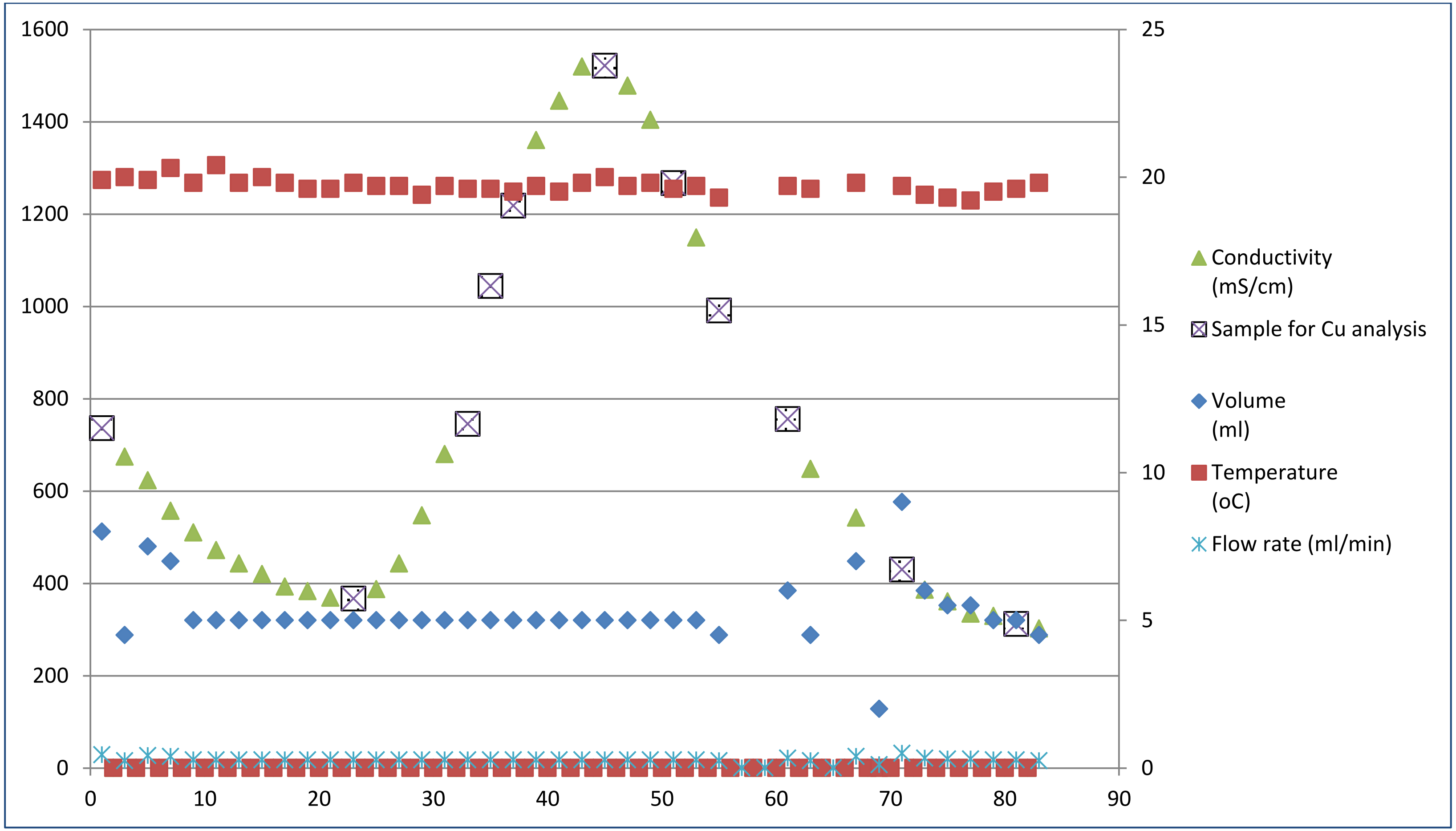
Particle Size Distribution of bottom soil material (TL 20 – 40cm)

Appendix 4a



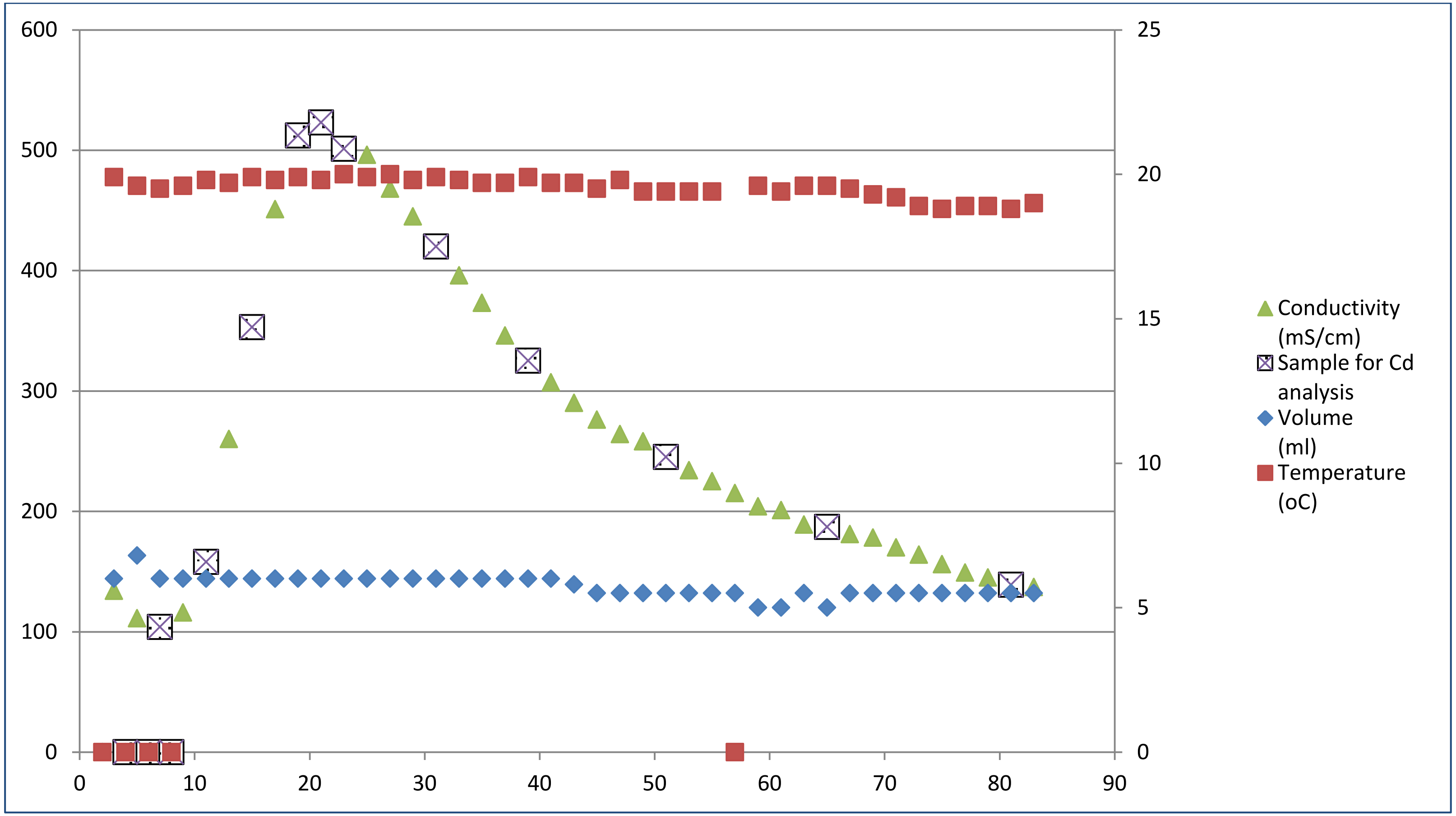
Graphical presentation of migration for Zinc (Zn) tracer experiment

Appendix 4b



Graphical presentation of migration for Copper (Cu) tracer experiment

Appendix 4c



Graphical presentation of migration for Cadmium (Cd) tracer experiment

Appendix 5

On-going chemical analysis for the experiment carried out at LNEC

(Analysing samples at UWS)

<u>Water samples</u> from LNEC soil-column tracer experiments for chemical analysis in UWS (Acidification 0.02ml HNO3 to 10ml aliquot; 0.06ml HNO3 to 30ml tracer solution) ICP-MS with reference material ERM – CA011b

Tracer experiment A: LNEC Zn

Sample no	Parameter to water analyse	Preservation
LNEC Zn #1	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #2	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #3	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #4	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #5	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #6	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #7	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #8	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #9	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #10	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Zn #11	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC UA Zn #12	F, Cl, NO2, Br, NO3, PO4, SO4(Using Dionex IC)	None
LNEC UA Zn #13	F, Cl, NO2, Br, NO3, PO4, SO4(Using Dionex IC)	None
LNEC Zn Tracer	Zn & other heavy metals (Using ICP-MS)	Acidified HNO3

Tracer experiment B: LNEC Cu

Sample no	**Parameter to analyse**	**Preservation**
LNEC Cu #1	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #2	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #3	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #4	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #5	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #6	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #7	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #8	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #9	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #10	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC Cu #11	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3
LNEC UA Cu #12	F, Cl, NO2, Br, NO3, PO4, SO4 (Using Dionex IC)	None
LNEC UA Cu #13	F, Cl, NO2, Br, NO3, PO4, SO4(Using Dionex IC)	None
LNEC UA Cu #14	F, Cl, NO2, Br, NO3, PO4, SO4(Using Dionex IC)	None
LNEC Cu Tracer	Cu & other heavy metals (Using ICP-MS)	Acidified HNO3

Tracer experiment C: UWS LW/H Cd

Sample no	Parameter to analyse	Preservation
LW/H Cd #1	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #2	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #3	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #4	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #5	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #6	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #7	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #8	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #9	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #10	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #11	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3
LW/H Cd #12	Cd & other heavy metals (Using ICP-MS)	
LW/H Cd #13	F, Cl, NO2, Br, NO3, PO4, SO4 (Using Dionex IC)	None
LW/H Cd #14	F, Cl, NO2, Br, NO3, PO4, SO4(Using Dionex IC)	None
LW/H Cd #15	F, Cl, NO2, Br, NO3, PO4, SO4(Using Dionex IC)	None
LW/H Cd Tracer	Cd & other heavy metals (Using ICP-MS)	Acidified HNO3

Leaching experiment D: UWS LW/H heavy metals

Sample no	Parameter to analyse	Preservation
LW/H #1	heavy metals present (Using ICP-MS)	Acidified HNO3
LW/H #2	heavy metals present (Using ICP-MS)	Acidified HNO3
LW/H #3	heavy metals present (Using ICP-MS)	Acidified HNO3
LW/H #4	heavy metals present (Using ICP-MS)	Acidified HNO3

Leaching experiment E: UWS US heavy metals

Sample no	Parameter to analyse	Preservation
UWS US #1	heavy metals present (Using ICP-MS)	Acidified HNO3
UWS US #2	heavy metals present (Using ICP-MS)	Acidified HNO3
UWS US #3	heavy metals present (Using ICP-MS)	Acidified HNO3
UWS US #4	heavy metals present (Using ICP-MS)	Acidified HNO3

Appendix 6

STSM Supervisor, Dr Teresa E. Leitão (on the right); STSM grantee, Ms Uche Chukwura (middle) & senior technician, Maria José Henriques (on left hand corner)

Friends and colleagues at LNEC & Uche Chukwura (on far right)

LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

04587 2013-11-18

REGISTADO

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Scotland, United Kingdom

Your reference	Your communication	Our reference	Date
		0111/41/21	

Subject: Training certificate

Following your Traineeship at LNEC, from October 15th till November 14th 2013, please find enclosed your Training Certificate.

Best regards

Head of the Technical and Public Relations Office

Manuela França Martins
Manuela França Martins
Técnico Superior

Encl.: 1 Training Certificate

LNEC LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

certificado de estágio

We certify that **Uchechukwu Ogugua Chukwura**

Took a traineeship at the

Water Resources and Hydraulic Structures Division
of the Hydraulics and Environment Department

From **2013/10/15** till **2013/11/14**

Lisbon, 14th November 2013

The Board of Directors

Carlos Pina
Presidente do LNEC