Vadose zone hydraulic conductivity monitoring by using an arduino data acquisition system

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***Abstract*—In this work the development of a continuous monitoring system for the hydraulic conductivity is presented. The system uses the measurement of temperatures in geological materials at different depths to calculate the water flux rates by using analytical solutions for the Stallman´s heat and fluid transport equation. Data from sensors are filtered and phase and amplitude information is extracted by using Digital Signal Processing techniques, such as DHR inside MATLAB environment. A column test was developed to evaluate the system performance and its results were compared against real infiltration data. Initial result shows a good performance (r-RSME = 0.08). After improvements, the system could be installed in the field to monitor water flux rates and hydraulic conductivity in intermittent rivers and areas considered as a recharge zones to study and quantify infiltration volumes.**

***Index Terms*—Dynamic Harmonic Regression (DHR), Hydraulic conductivity, Stallman equation**

I. INTRODUCTION

Although the 75% of the earth´s surface is covered with water, only the 2.5% correspond to fresh water [1], and, from the total volume of fresh water, the 1% is superficial water, 29% is groundwater and the rest isn't available because it is in form of snow and glaciers [2]. However, due to the population growth and water pollution, the extraction of groundwater has been increased dramatically during the last years. In Mexico for example, the 60.7% of the total water used comes from aquifers with an estimated extraction rate of 205.1 m^3/s; consequently 101 of 653 administrative aquifers of the country have been reported with some level of overexploitation [3]. Because of this, the study of aquifer´s recharge and discharge processes is an important subject for the scientists all around the world.

Hydraulic conductivity which is a measurement of the porous media permeability [4] is an important parameter during the aquifers recharge process and its estimation along the vadose zone (zone between the ground surface and the aquifer) is a difficult task due to the high spatial and temporal variability. Methods to estimate hydraulic conductivity can be classified in different ways depending of the authors; however, a general classification divides them in two groups: direct and indirect methods. Direct methods include devices such as infiltrometers, seepage meters and lysimeters; indirect methods includes the use of tracers (such as isotopes or heat) and numerical modelling. Direct methods provide results in a short term, numerical modelling involves deep analysis of porous media physical properties and such properties as well as indirect methods show high spatial and temporal variability.

Since the development of Stallman's equation for heat and fluid transport in 1965 [5], several researches have been realized along the years and even so, this is a young field to research [6]. The main advantage of the heat usage as tracer is that the thermal properties of soils have a narrower range of variation than their analogous hydraulic properties [7].

Even when researches have been done, it is necessary the development of easier and cheaper ways to measure, record, process and determinate water fluxes so it can be extended all around the country to provide accurate information for water management.

In this paper, preliminary results of one porous media hydraulic conductivity monitoring system are presented. Temperature time series are collected by a low cost acquisition system, then, time series are filtered, processed, and phase and amplitude ratios are calculated by using Dynamic Harmonic Regression (DHR), and finally, water flux rates are determined using the analytical solutions developed by Hatch et al. [8].

This paper is organized as follows: section 2 describes the theory behind the use of the heat as a natural tracer and techniques for filtering and fundamental signal isolation. Section 3 describes the experiment setup and parameters estimation. Section 4 describes the results and model performance. Finally, in section 5 some concluding remarks and future works are given.

II. THEORETICAL DESCRIPTION

A. The heat and fluid transport

Since de beginning of the 20th century, some researchers such as Bouyoucos (1915) [9], recognized heat transference together with the vertical water flow through sediments and porous media. Heat is transferred through vadose zone mainly by conduction and convection. Stallman´s equation (1) defines one-dimensional, anisothermal and vertical flow of an incompressible fluid through isotropic, homogeneous porous medium; it includes heat flux by conduction and advection,

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