EXPLORING THE GROUNDWATER HYDROGRAPHS OF CHOU-SHUI CHI ALLUVIAL FAN BY LINEAR SIGNAL MODEL (LSM)

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ABSTRACT

The over-pumping of groundwater for satisfying the water demand for agriculture, aquaculture, industrial, and domestics uses in the central region of Taiwan has caused the imbalance groundwater level and a large scale land subsidence. However, the demand for groundwater resources is increasing, and it is impossible, currently in Taiwan, to completely ban all pumping. There is urgent need to understand situation in the central Taiwan since several decades. In order to explore the groundwater hydrograph of Chou-Shui Chi alluvial fan, this research proposes establishing the Linear Signal Model (LSM) for groundwater by using the groundwater fluctuation level data and the rainfall event data observed in the Chou-Shui Chi alluvial fan for the past decades. Then, the LSM is used to identify the main pumping characteristics from the groundwater observation data and also simulate the variation of the groundwater level. By using LSM, four parameters, which are the natural loss, the recharge coefficient, the artificial pumping coefficient and the groundwater reference level, will be generated with different physical meaning, and this study will try to understand the impact of those parameter on the groundwater system. The achievement of this study prove that LSM can be used for groundwater prediction and describe an aquifer characteristic. The most relevant is the groundwater reference level (h_b), our result demonstrate that h_b can be used as the groundwater reference level in order to avoid the over-pumping that may lead to land-subsidence.

Keywords: *artificial pumping, Linear Signal Model (LSM), Pumping Recovery Strength (PRS), groundwater reference level (h_b), Chou-shui Chi alluvial fan*

1. INTRODUCTION

Due to the over-pumping in Taiwan, several researchers have focused their studies on pumping source identification to understand and control over-pumping (Chen et al. 2010; Hsiao et al. 2017; Liu, Hsu, and Yeh 2015). In this study, we approach a new method for regional pumping characterization and quantification. Since it is impossible to identify the pumping activity of each pumping well, we introduce the concept of the Pumping Recovery Strength (PRS). The Linear Signal Model (LSM) analysis can be applied to identify the main pumping characteristics from the groundwater observation data. Then LSM can be used to simulate variations of the groundwater level and evaluate the average pumping quantity. We apply the proposed method to a regional aquifer system in the Chou-Shui Chi alluvial fan in central-western Taiwan.

By using the Linear Signal Model of groundwater, we will try to set a groundwater level lower limit for pumping so that the over-pumping can be prevent, and the reference value of water consumption in the controlled area of a single observation well is put forward to meet the demand of effective utilization and water conservation of groundwater resources, while land subsidence (Hung et al. 2012) may slow down with a reasonable artificial pumping rate.

2. METHODOLOGY

2.1 Pumping Recovery Strength

For the source identification we must estimate the amount of pumping and the locations of the pumping sources (Hsu et al. 2013). The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring drawdown as a function of time. These measurements are then integrated into an appropriate well-flow equation to calculate the hydraulic parameter of the aquifer. It can be applied by a single-well or multi-well (observations). However, for a large-scale area it is challenging to get the pumping index. Due to the current lack of reliable records for groundwater pumping, since human behavior is mostly characterized by sunrise and sunset, we assume that the significant frequency for pumping is daily because farmers always pump at daytime (groundwater decreases) and take rests at night (groundwater raise). The more pumping, the larger the drawdowns and the larger the amplitude of daily frequency (Figure 1). This is the Pumping Recovery Strength (PRS). Based on the concept, we use short-time Fourier transform (STFT) to determine the PRS which is possibly a linear index of the artificial pumping.

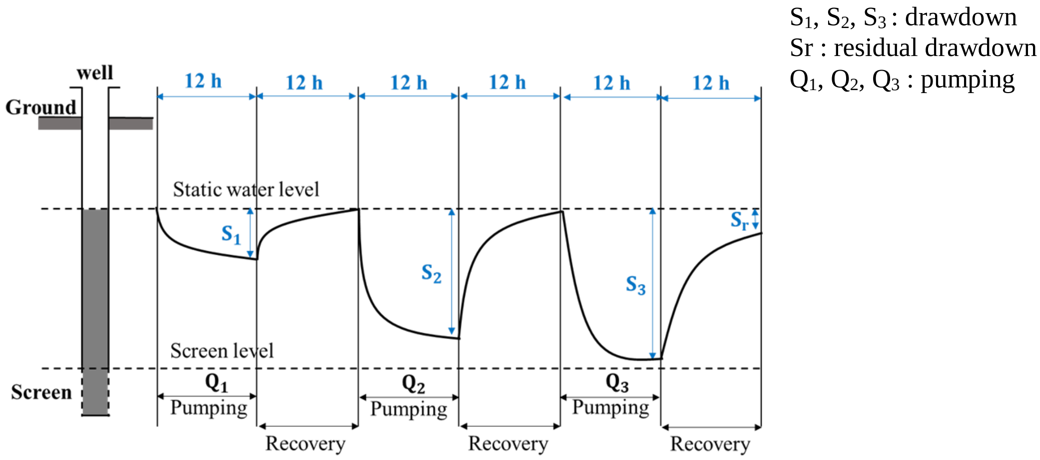


Figure 1. The Pumping recovery test with non-connected steps

2.2 Linear Signal Model (LSM)

This research proposes establishing the Linear Signal Model (LSM), which is executed automatically by **Visual Signal** (figure 2) (Visual Signal is a signal processing software developed by AnCad Inc. (2011) company to provide time-frequency analysis solutions in an intuitive way), for groundwater by using the groundwater fluctuation level data and the rainfall event data observed in the Chou-Shui Chi alluvial fan for the past decades. Using LSM for the groundwater prediction a pair of data, hourly rainfall data and groundwater fluctuation level are required. A good fitting will confirm the correlation between groundwater and the rainfall. Considering the pumping and the recharge effects as sources and sinks for the groundwater and assuming that without any recharge and pumping the groundwater will be naturally lost from an aquifer to another system, we express the groundwater movement as a partial differential equation (PDE), after derivation, the groundwater Linear Signal Model equation is obtained:

$$\frac{\partial h}{\partial t} = -\lambda(h(t) - h_b) + \gamma R(t) - \sigma P(t) \quad (1)$$

Where, R(t) [L/T] and P(t) [L/T] represent the rainfall infiltration and artificial pumping respectively and the associate parameter ϒ and σ relates to rainfall infiltration and pumping equivalency. The pumping effect can be approximated via PRS (Pumping Recovery Strength).

The dissipation coefficient (λ) represents the time constant of how long water has been kept in the system, the rainfall infiltration coefficient (ϒ) converts a fraction of observed precipitation effectively injected into groundwater reservoirs and the pumping conversion coefficient (σ) converts a fraction of observed pumping effectively out of groundwater reservoirs.

There are four parameters in the derived LSM which are h_b, λ, ϒ, and σ. h_b with dimension [L], λ with dimension $[\frac{1}{T}]$, ϒ and σ are dimensionless.

Then, the LSM is used to identify the main pumping characteristics from the groundwater observation data and also simulate the variation of the groundwater level. By using LSM, four parameters, which are the natural loss, the recharge coefficient, the artificial pumping coefficient and the groundwater reference level, will be generated with different physical meaning, and this study will try to understand the impact of those parameter on the groundwater system.

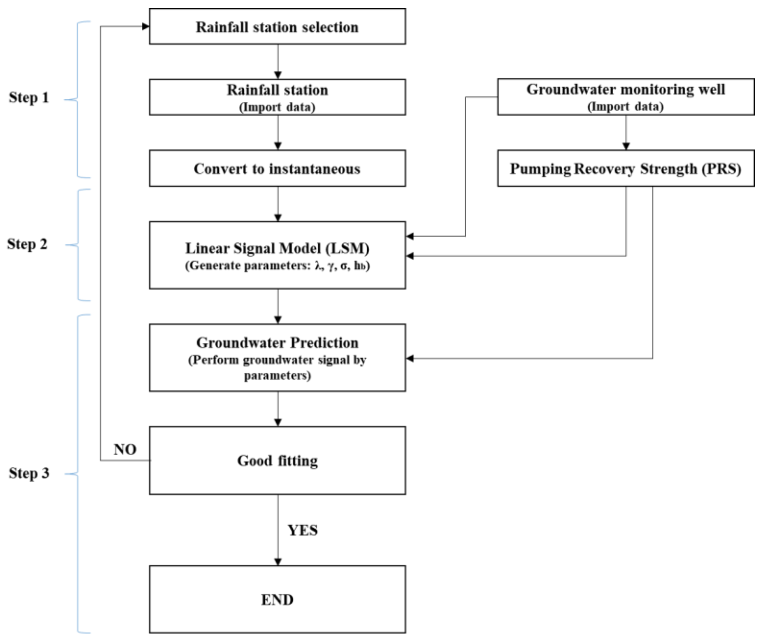


Figure 2. The Linear Signal Model (LSM) steps for groundwater level fluaction prediction in the time

3. Case study: Chou-shui Chi alluvial fan

3.1 Presentation of Chou-shui alluvial fan

Situated in central region of Taiwan, Chou-Shui Chi watershed is the largest basin in Taiwan. The Chou-shui river is about 188 kilometers long and the area of the watershed covers 3240 km^2. With a total area of 2079 km^2, it consists of Chou-Shui river basin in the southern part and Wu River basin in the northern part. The natural geographical boundaries delimit the Chou-shui-wu river basin, it consists of the Taiwan strait in the west, Wu River in the north, Pei-Kang River in the south and the Western foot hill in the east.

3.2 Groundwater prediction

In order to analyze the impact of the pumping for agriculture purpose in the groundwater and due to the fact that farmer usually pump groundwater at the first layer to cut cost, this study will only focus on F1 aquifer. Fourteen groundwater observation well stations and six rainfall station have been used in this study.

4. DISCUSSION AND CONCLUSION

The result of this study match with the geographical structure, which proves that LSM can be used for groundwater prediction and describe an aquifer characteristic (Figure 3). The result of the groundwater reference level (h_b) is also relevant, it demonstrates that h_b can be used as the groundwater reference level in order to avoid the over-pumping that may lead to land-subsidence (Figure 4,5,6).

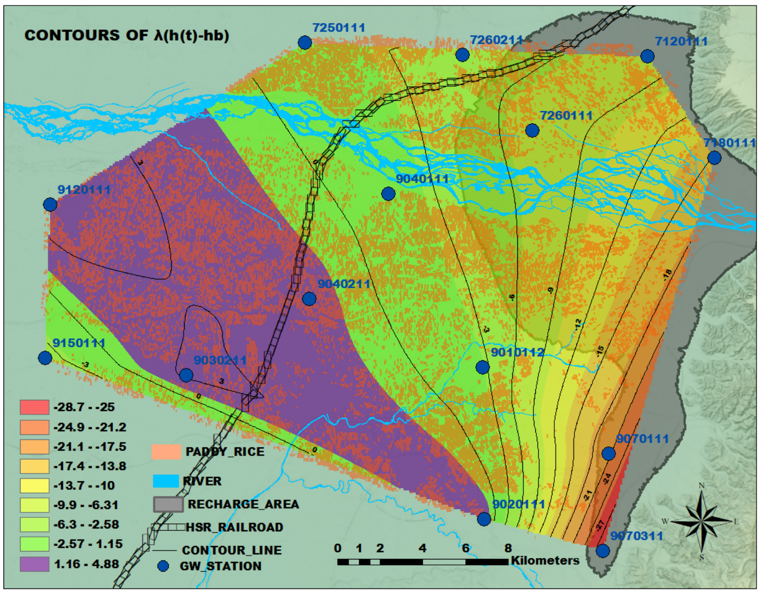
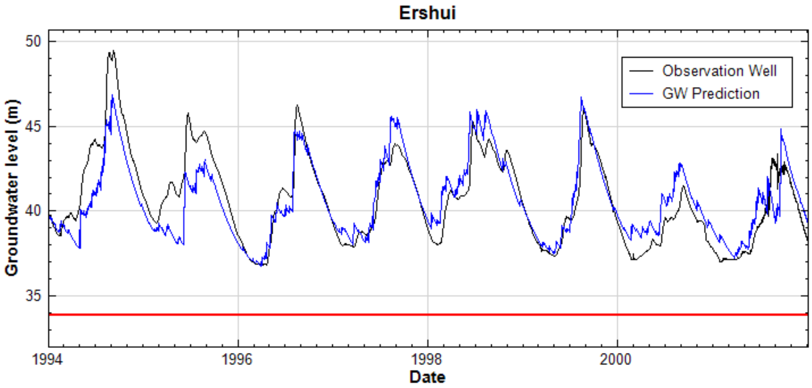


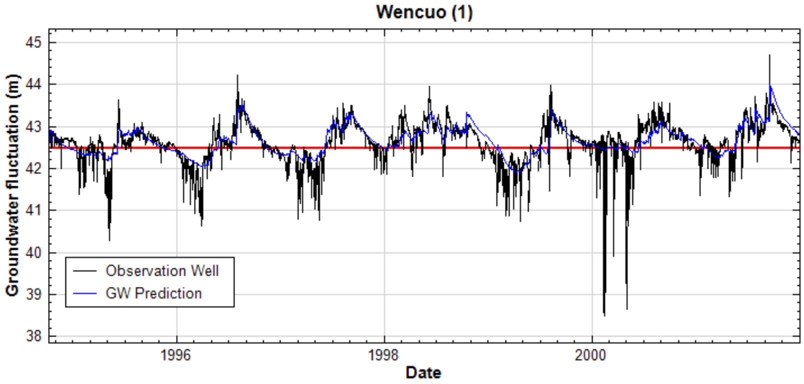
Figure 3. The contour map of the natural loss including the HSR railroad, the paddy rice and the recharge area of the alluvial fan

On the figure 4,5,6 below the red line stand for the groundwater reference line h_b, the black line for the observed groundwater level and the blue line for predicted groundwater level.



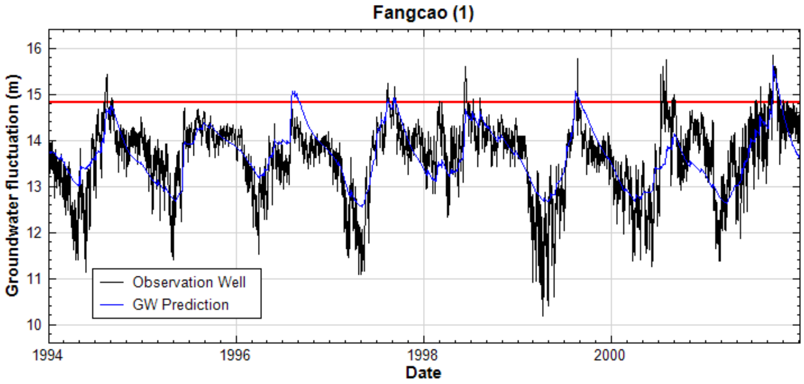
The aquifer is suitable for pumping and the risk of land subsidence due to over-pumping is very low

Figure 4. The groundwater level is higher than h_b



There is risk of land subsidence, the pumping during the dry season should be stopped or control to don't be under h_b

Figure 5. The groundwater level is lower than h_b during the dry season



The land already subside and this aquifer cannot be use for pumping any more

Figure 6. The groundwater level is under the h_b

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