Master Thesis Proposal

A Proposal to Develop a Harmonic Interference Test for Aquifers

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I. Introduction

It is important to continue improving techniques that enable the hydrogeologist to manage groundwater. This is important for the sake of maintaining the quality and sustainability of this resource. In this proposed study I intend to present a test that is more precise and can be used to test a broader geographical area than the current slug-type methods for source and observation well interference testing. This improvement involves the development of a sinusoidal hydraulic wave. The cyclical application of stress within a wellbore in the configuration of a sinusoidal hydraulic wave, which is in "harmony" with the aquifer's physical properties, will result in a wave that will travel greater distances with greater definition than that produced in current slug tests.

Well interference testing originally was performed by continuous pumping from a source well while simultaneously recording the concurrent drawdown in an observation well. This type of test required installing a pump in the source well and supplying this pump with a significant amount of electrical power and sufficient piping to convey the water to a place where it would not be a nuisance. Drawdown was then measured at the observation well during the pumping of the source well. While this test is still used and generally accepted as the most accurate method to determine the properties of an aquifer between a source and an observation well, it can be a cumbersome and expensive procedure.

A current alternative to the pumping test is a well interference test which employs a hydraulic pulse artificially generated within the source well. In this procedure the source well is stressed either by the injection or withdrawal of a relatively small "slug" of water or a solid material. After the slug is applied or removed, the subsequent rise or fall of head in the observation well is measured. Using this information, the hydrologic properties of the formation being tested can be determined. The advantage of this type of test over the pumping test is the decrease in the amount of equipment needed and the resultant savings in time, money and disruption of the surrounding area. The limitation of using a slug type test is the resultant collection of data is representative of a smaller geographical area than in the pumping test.

My goal is to improve the slug interference test so that this non-pumping test covers a much larger geographical area than the 100 feet that Spane (1996) thought possible. This will be done by finding and utilizing the formation's "harmonic" period.

II. Related Literature

Very little literature in the field of groundwater is available on cyclical slug interference testing. The closely related non-cyclical slug test and the lesser used slug interference test have been in use for several decades, and a great deal of research has been done on them. As a result, there exists a large pool of literature on almost every aspect of slug and slug interference testing. The idea of a slug test first came from Hvorslev (1951) and from Ferris and Knowles (1954), and interpretations of the results of this test were made easier with the development of type curves by Cooper, Bredehoeft, and Papadopulos (1967). Since that time researchers have continued to find and correct minor flaws in the test, all seemingly with the intent of showing that this test is a simple and accurate alternative to the pumping test and, in many cases, the preferred test. Efforts have continued to make test data analysis simpler, including Singh (2001) who developed a method to determine aquifer properties from slug test data using only a handheld calculator. The radius of influence of this test has been considered by researchers ranging from Black (1981) to Hayashi (1987); the problems of the effect of wellbore storage on test results have been reviewed and several solutions have been offered by researchers ranging from Prats (1975) to Novakowski (1989). Spane (1996) has systematically shown the effect on this test of each of five major variables: transmissivity, storativity, specific yield, vertical anisotropy, and wellbore storage. He was also of the opinion that, under favorable conditions, the slug interference test is comparable in quality to the pumping test when the source and observation wells are within 100 feet of each other.

No articles were found in the literature which discussed the use of cyclical sinusoidal waves that are generated with the intent of producing harmonic waves in aquifers. Although Walter (1982) first suggested the use of repeated slug test pulses, it was not for the purpose of taking advantage of an aquifers harmonic period. The only work found that discusses the usefulness of the cumulative effect of cyclical pulses was a non-reviewed paper by Hocking (2001). Hocking saw the potential for testing the effectiveness of barriers using cyclical pulses. He clearly saw potential for additional research for this type of procedure but, as with most previous work, he was working with a square wave pulse, not a sinusoidal wave.

Van der Kamp (1976) did address sinusoidal waves in an aquifer. His paper was presented as a solution to one circumstance of a slug test, but it was actually a paper on the relationship between aquifer properties and the properties of the oscillating waves that are often created when a well is stressed by a sudden change in head. While he did not suggest creating sinusoidal waves for aquifer evaluation, he did analyze the waves that are inadvertently created in many slug tests and he formulated the relationship between the properties of the waves and those of the aquifer. This is likely the most relevant and therefore useful article for my research.

The significance of this proposed project is very clear in view of how little research in the groundwater field has been done on cyclical harmonic interference testing in aquifers. Most of the necessary tools for analyzing the results of this testing method are already in place as a result of the work previously done in the area of slug and slug interference test research.

III. Methodology

This study will require three steps to show the soundness of my proposal. The first is to design and build a device that will produce the desired set of signals. The second is to design a test that will incorporate this set of signals and produce useful data. The third is the analysis and interpretation of this data.

A. Apparatus

The device required to accomplish this work will consist of a mechanism that will actually perform cyclical slug-in and slug-outs of a slug (see figure 2). The slug will consist of a 30 inch long piece of 1½ inch pipe which will displace approximately 53 cubic inches of water. This device will be used to create cyclical stresses over an adjustable range of wave periods. A transducer in the source well will be used to record the shape and timing of the pressure wave created. The fabrication of this ‘wave generator’ will utilize existing commercially available components with all custom fabrication performed by myself. A variable frequency drive will be utilized to vary the speed of the electric motor in order to vary the period of the wave that is produced.

The setup in each observation well will consist of one packer with a pressure transducer in the wellbore below the packer. A packer will be used in this fashion to eliminate wellbore storage effects. The signal from the transducer will be continuously logged and correlated with the data from the source well.

B. The Test

The Wave Generator will be set up to operate in well MW-1A. Wells MW-2A and DWR02-MW-3A will be set up as observation wells. The first test will be a single slug-out. This will be used to see if Van der Kamp's solution holds true for an observation well. In the second test, the Wave Generator will produce waves with a period of 4 seconds for a duration of ½ hour. Each successive ½ hour session will see an increase in wave period of 1 second up to 20 seconds. At this point, each ½ hour session will see increases of wave periods of 5 seconds up to a total of 100 seconds.

C. Data Analysis

There will be two goals in my data analysis:

1) To determine if Van der Kamp's solution holds true for an observation well
2) To determine if there exists a particular period for which a sinusoidal wave will travel further in this aquifer and, if so, how much further

To determine the answer for goal 1, I can apply the known transmissivity of the aquifer and the known wellbore measurements into Van der Kamps solution in order to predict the angular frequency and the damping constant (ώ & γ). Then ώ & γ can be measured from the single slug-out that was performed.

To determine the answer for goal 2, I can measure the amplitude of the waves created in each of the ½ hour sessions as they are sensed in the observation wells. The wave period that produces the largest amplitude wave will be used to calculate ώ & γ. ώ & γ will then be used in the Van der Kamp solution in order to calculate the predicted transmissivity and observation wellbore properties. Additionally, once the period is known that produces the largest amplitude, this wave will be generated again at that frequency and transducers will be used in each of the campus wellfield wells that are screened in the same aquifer to determine the maximum usable distance for this wave.

IV. A Description of Potential to Accomplish the Project

This undertaking requires knowledge in each of three areas: a knowledge of mechanical fabrications and instrumentation, a knowledge of the state of understanding of aquifer properties and how they respond to tests similar to the one I am proposing, and a knowledge of methods of research.

I have personally worked in most areas of metal fabrications as a welder, designer, supervisor, project manager, and contractor. My experience consists of installing many types of water (and other fluids) related equipment including hydroelectric turbine generators, water treatment equipment, steam generating equipment, hydraulic control systems, digital control systems, and conducting cost estimates. From my experience, I know that the manufacturers and suppliers of the type of products needed for this project are very cooperative in helping to find the correct components for the application.

Through the literature review that I have already completed, I have a good understanding of the state of the knowledge in my field of research. And, through the course work I have completed, I have a good comprehension of the framework required for appraising the properties of aquifers and for understanding the methods for determining these properties when they are not known.

Therefore I anticipate that, with the permission from the CSUS Geology Department, I will succeed at this project with results beneficial both to my department and to the hydrogeology community.

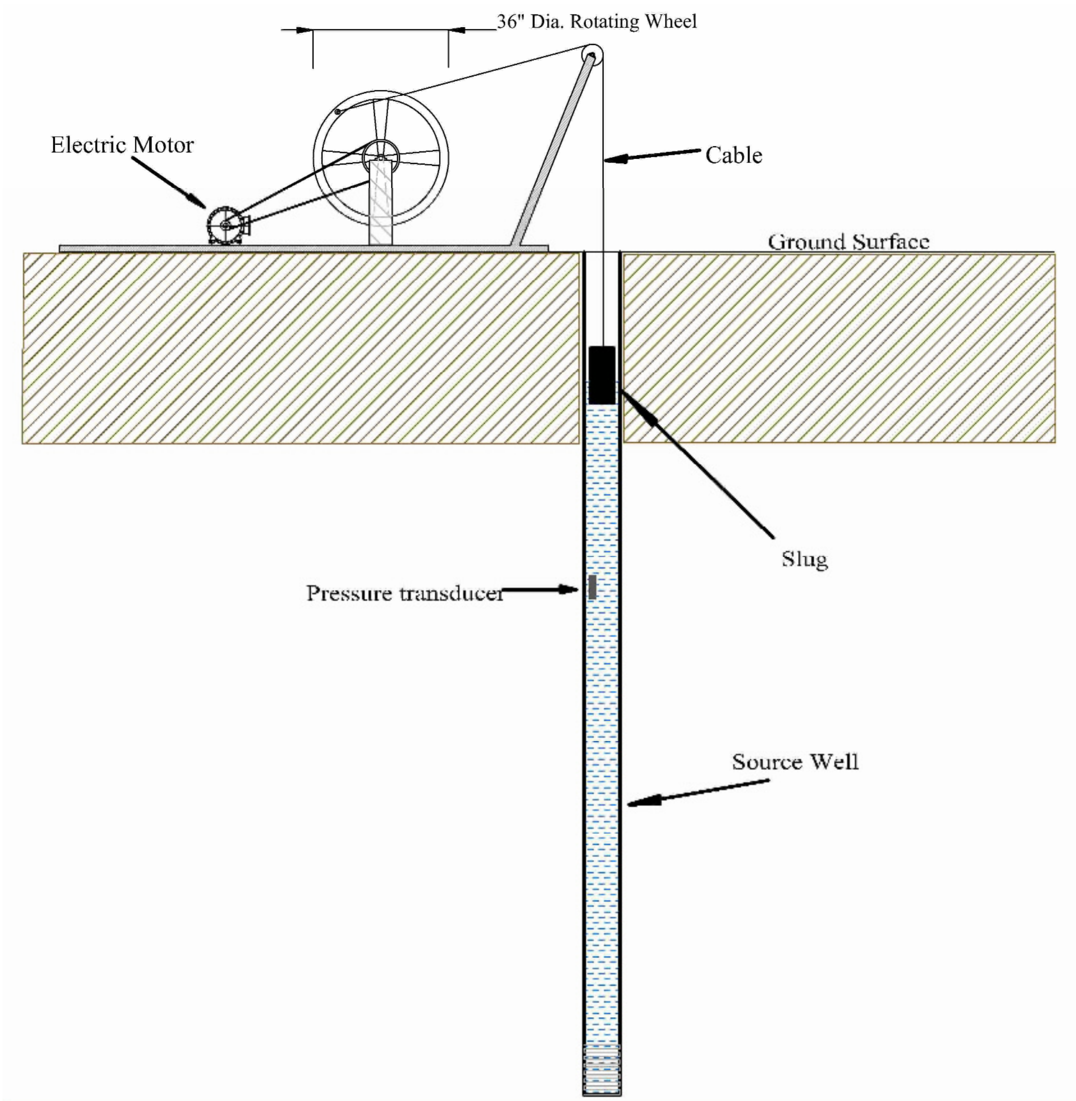
V. A Plan for Scholarly Dissemination

The finished thesis will be made available to the public by being placed in the CSUS library along with other theses produced by CSUS students. If I determine that the results found in this study would be of interest or benefit to the groundwater community, then the thesis will be adapted and submitted to a journal that deals with aquifer related science.

VI. Tables, Charts and Figures

(see following pages)

Figure 1



36" Dia. Rotating Wheel
Electric Motor
Cable
Ground Surface
Slug
Pressure transducer
Source Well

VII. References

Black, J. L., and K. L. Kipp, Determination of hydrological parameters using sinusoidal pressure tests: A theoretical appraisal. Water Resour. Res., 17(3), 668-692, 1981.

Bredehoeft, J. D., and S. S. Papdopoulos, A method for determining the hydraulic properties of tight formations. Water Resour. Res., 16(1), 233-238, 1980.

Cooper, H. H., J. D. Bredehoeft, and I. S. Papadopulos, Response of a finite-diameter well to an instantaneous charge of water. Water Resour. Res., 3(1), 263-269, 1967.

Furcola, N. C., and others, Standard test method for determining transmissivity and storativity of low permeability rocks by in situ measurements using the pressure pulse technique. ASTM standards on ground water and vadose zone investigations, D4631-95, 213-219, 1994 (reapproved 2000).

Ferris, J. G. and D. B. Knowles, The slug test for estimating transmissivity. U.S. Geol. Sur. Ground Water Note 26, 1-7, 1954

Hayashi, K., K. T. Ito, and H. Abe, A new method for the determination of in situ hydraulic properties by pressure pulse tests and application to the Higashi Hachimantai geothermal field. J. of Geophysical Res., 92(9), 9168-9174, 1987.

Hocking, G., Hydraulic pulse interference tests for integrity testing of containment and reactive barrier systems. http://www.containment.fsu.edu/cd/content/pdf/218.pdf

Hvorslev, M. J., Time lag and soil permeability in ground-water observation. Bulletin 36, Vicksburg, Missippi: Waters Exp. Sta., U.S. Army Corps of Eng. 1951

Novakowski, K. S., Analysis of pulse interference tests. Water Resour. Res., 25(11), 2377-2387, 1989.

Prats, M., Effect of wellbore storage on pulse test pressure response. J. of Petroleum Tech., 27, 707-709, 1975.

Singh, S. K., Confined aquifer parameters from temporal derivative of drawdowns. J. of Hydraulic Engineering-ASCE, 127(6), 466-470, 2001.

Spane, F. A., Applicability of slug interference tests for hydraulic characterization of unconfined aquifers: (1) Analytical assessment. Groundwater, 34(1), 66-74, Jan-Feb., 1996.

Van der Kamp, G., Determining Aquifer Transmissivity by Means of Well Response Tests: the Underdamped Case. Water Resour. Res., 12(1), 71-77, 1976.

Walter, G. R., and G. M. Thompson, A repeated pulse technique for determining the hydraulic properties of tight formations. Groundwater 20(2), 186-193, 1982.

Wylie, A. and Magnuson, S., Spreadsheet Modeling of Slug Tests using van der Kamp Method. Ground Water vol. 33, No.2, 326-329, 1995

http://water.usgs.gov/pubs/of/ofr02197/ USGS Home for Slug Test Spreadsheets, including Van der Kamp

Schedule of Time by Task

Milestone	**Completion**
Thesis proposal accepted	12/21/04
Design of pulse generator	01/30/05
Thesis committee selected	02/10/05
Pulse generator fabrication completed	02/15/05
Data collection completed	04/01/05
Research completed	05/01/05
Draft thesis approved	08/01/05
Final thesis submitted	09/01/05
Thesis defense	09/30/05

Budget

Callout	Qty	Description	Notes/Part Number	Price
	1	110v electric motor		$100
	1	Variable frequency drive		$250
	1	Pulleys & hardware		$200
	1	Misc steel		$50
	1	Welding supplies		$15
	5	Pressure transducers	Already in possession from CSUS Geology	n/c
	3	Loggers – 0.05mVDC, 0.2sec interval recording	Needed from CSUS Geology	n/c
	1	2” inflatable packer	Already on loan from Bryan Downing	n/c
	1	4” inflatable packer	Needed from CSUS Geology	n/c

Budget Summary

Estimated costs for individual components are listed in the parts listed above. Cost estimates are based on availability from CSUS Geology Department of the necessary packers and data loggers. Fabrication required for the wave generator will be performed by myself at no monetary cost to the project. Help should not be required during the performance of tests in the field. Except for items provided by CSUS Geology, this project can and will be self-funded.

Principal Investigator

Art Reed