Report as of FY2007 for 2006GU76B: "Response of Well Heads of the Northern Guam Lens Aquifer to Rainfall and Sea Level Fluctuations at Daily Resolution"

Publications

Project 2006GU76B has resulted in no reported publications as of FY2007.

Report Follows

PROJECT SYNOPSIS REPORT

Project Title: Response of Well Heads of the Northern Guam Lens Aquifer to Rainfall and Sea Level Fluctuations at Daily Resolution

Problem and Research Objectives

This project was an intensive one-year study of newly acquired daily values of well head, rainfall, and sea level. Data has been obtained for other wells that were not available in previous research efforts (Lander et al. 2001). Substantial preparatory work was done to properly format all data in a side-by-side daily order, for ready analysis and comparison. The immediate objective was a set of statistical model predictions of the daily value of the head at each well using the values of the daily rainfall and daily sea level. The parameters (e.g., coefficients for the rainfall response curve, coefficients for the sea level response, the constraints applied to the outflow, and the numerical value of the floors on the predicted head) that optimize these predictions will give insight into the hydraulic and geological properties of Guam's northern lens aquifer. Of particular interest will be to document the well responses to pulses of heavy rainfall, and the nearly step-function drops of sea level that occur after the close passage of typhoons. There are several pulse occurrences of substantial rainfall, and rapid rises and falls of sea level in response to typhoons and to El Niño. The response of the wells to these extreme events will be benchmark tests of any numerical model simulation of the NGLA. This study provides baseline information for identifying the physical properties of the aquifer, and their implications for numerical simulation of the NGLA and for Guam's water management plan. Recent acquisition of rainfall, sea level, and wellhead data at *daily* resolution — plus the acquisition of data for several more wells than were used in the previous study (Lander et al. 2001) — has allowed a more in-depth analysis of the well hydrograph responses to variations in the rainfall and sea level. For example: a highly accurate prediction of the daily hydrograph of Well A20 in Ordot was made using only the daily rainfall data obtained at the Guam International Airport. Correlations between the predicted well head and the observed well head exceeded +.90 (Fig. 1).

Moving to the wells of the northern Guam Lens Aquifer, very different response characteristics to rainfall are found than at the Ordot Well (A20). Whereas Well A20 is in argillaceous limestone, has an elevated wellhead (15 meters above sea level), and shows no response to changes in sea level; the wells in the north are in limestone of higher permeability, they have a head that is near sea level, and the head responds to variations in sea level. The response of the northern wells to rainfall pulses is much faster than at A20. Using the same well-as-reservoir approach for the response of the northern wells to the time series of daily rainfall yields less skillful predictions (Fig. 2).

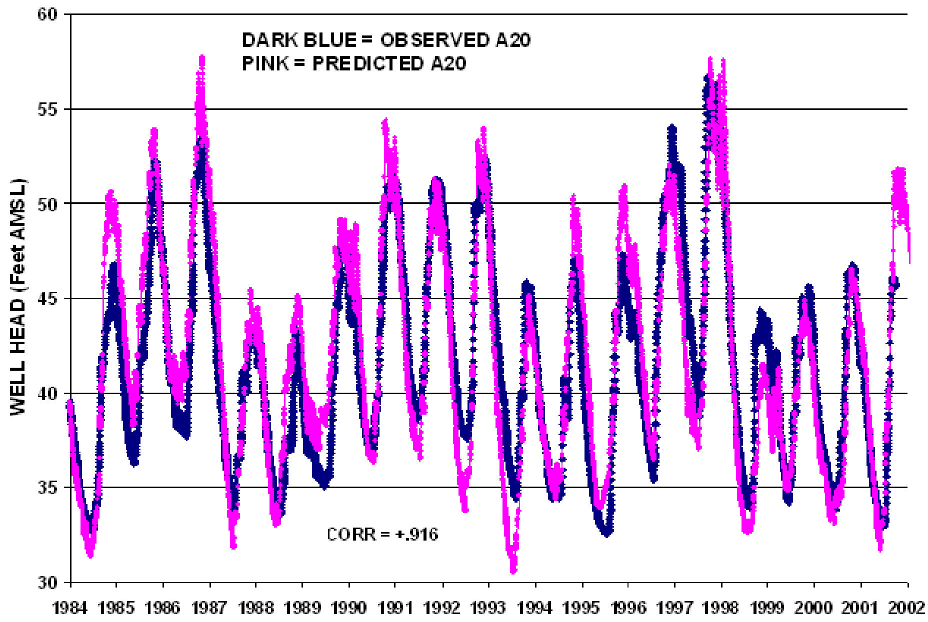

Figure 1. A comparison of the observed A20 well hydrograph versus the predicted hydrograph.

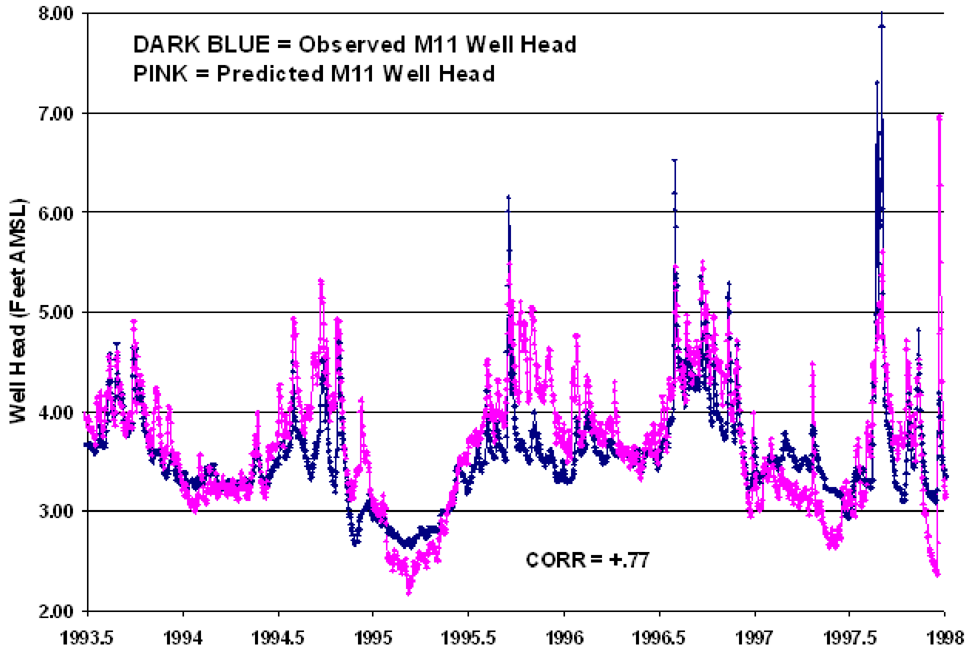

Figure 2. Predicted (pink time series) and observed heads (dark blue time series) for Well M11. The predicted time series was based on daily rainfall and sea level data.

Methodology

Instead of using correlation analysis to determine the relationships among wellhead rainfall and sea level (as in Lander et al. 2001), a conceptual model of the well-as-reservoir was used. The wellhead was assumed to respond to the rainfall in the same manner as a reservoir, with the changes in the storage (i.e., gage height, S) in the model reservoir given by:

$$\Delta S = \text{Inflow} - \text{Outflow} \quad (1)$$

The outflow was assumed to be proportional to the Storage or gage height, S:

$$\text{Outflow} = k\,(S - \text{Floor}) \quad (2)$$

Where k is a constant, and “Floor” is the base level below which no outflow occurs.

The observed daily rainfall at the Tiyan WSO was used as the inflow to the reservoir. With suitably chosen constants, and a floor beneath which no outflow was allowed to take place, the predicted water level in the model reservoir matched the well head of A20 very closely.

The finite difference integration of the following equation yielded the predicted A20 well head in Fig. 1:

$$(\text{Well head})\ D = (\text{Well head})\ D\text{-}1 + K1\ (\text{Rain}) - K2\ ((\text{Well head})\ D\text{-}1 - \text{Floor}) \quad (3)$$

Where D = Day; and K1, K2, and “Floor” are constants.

A further refinement of Equation (3) to include a delayed response to the rain at time lags of up to one month yielded even better predictions (not shown).

An additional constraint on the values of the coefficients was for them to accurately replicate the short-term response to extreme daily rainfall events (Fig. 4). The problem thus becomes one of optimizing the performance of the predictions in a multidimensional phase space that includes: (1) the correlation coefficient between the predicted wellhead and the observed wellhead for the entire time series, (2) the match of the predicted wellhead versus the observed wellhead response for selected extreme daily events, and (3) the mean absolute error between the predicted wellhead time series and the observed wellhead time series. The mathematics of analyzing this phase space for local and global minima was beyond the scope of this project, but values were chosen manually that gave satisfactory results on the graphical presentations of the time series. Cross correlation values between the predicted wellhead time series (12 years) and the observed time series exceeded +.90 for well A20, and +.75 for the M series wells, while retaining fidelity to the observed wellhead responses to extreme daily rainfall events.

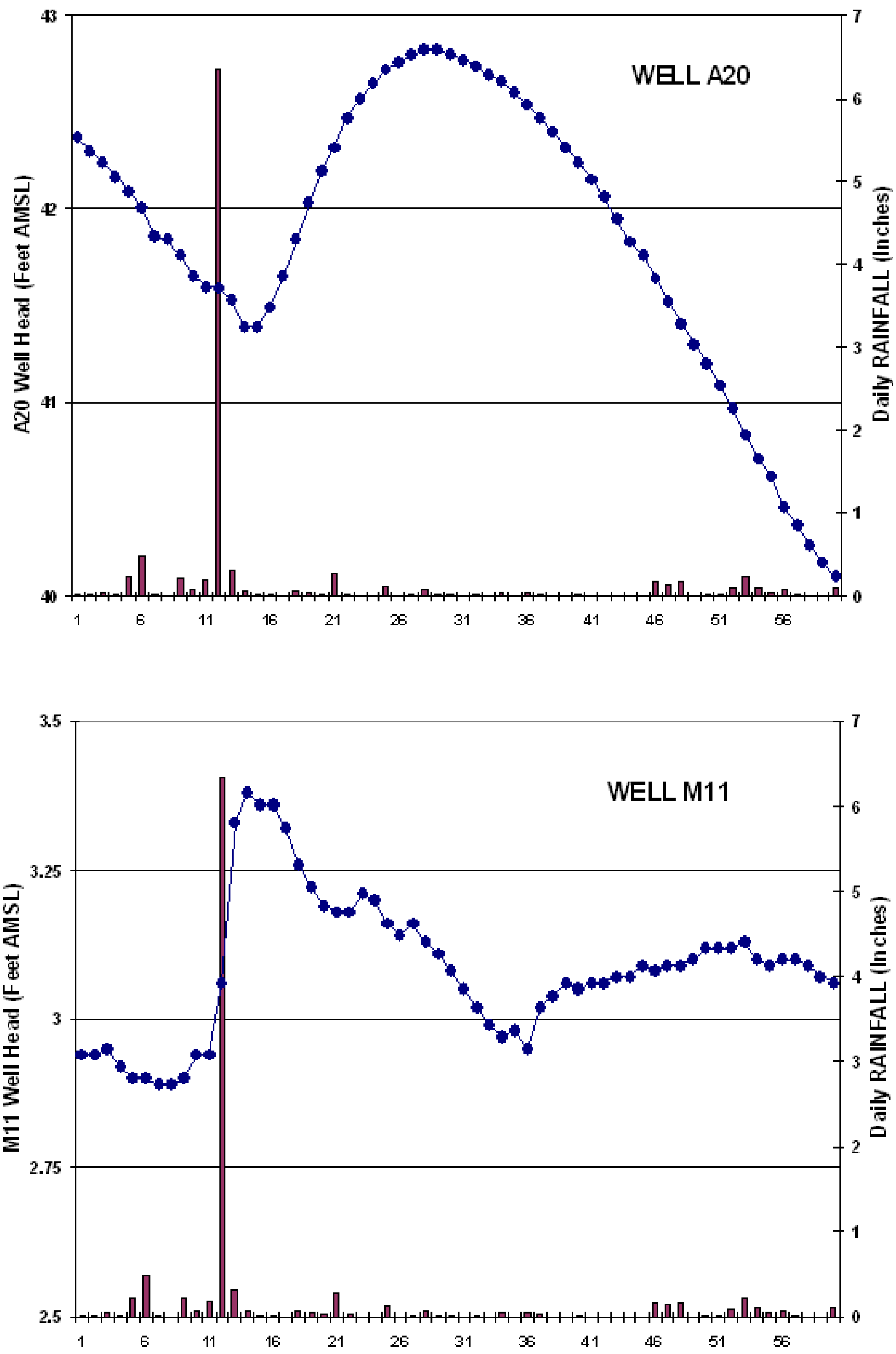

Figure 3. The response of Well A20 (top panel) and Well M11 (bottom panel) to a pulse of heavy rain (6 inches) that occurred on January 12, 1988.

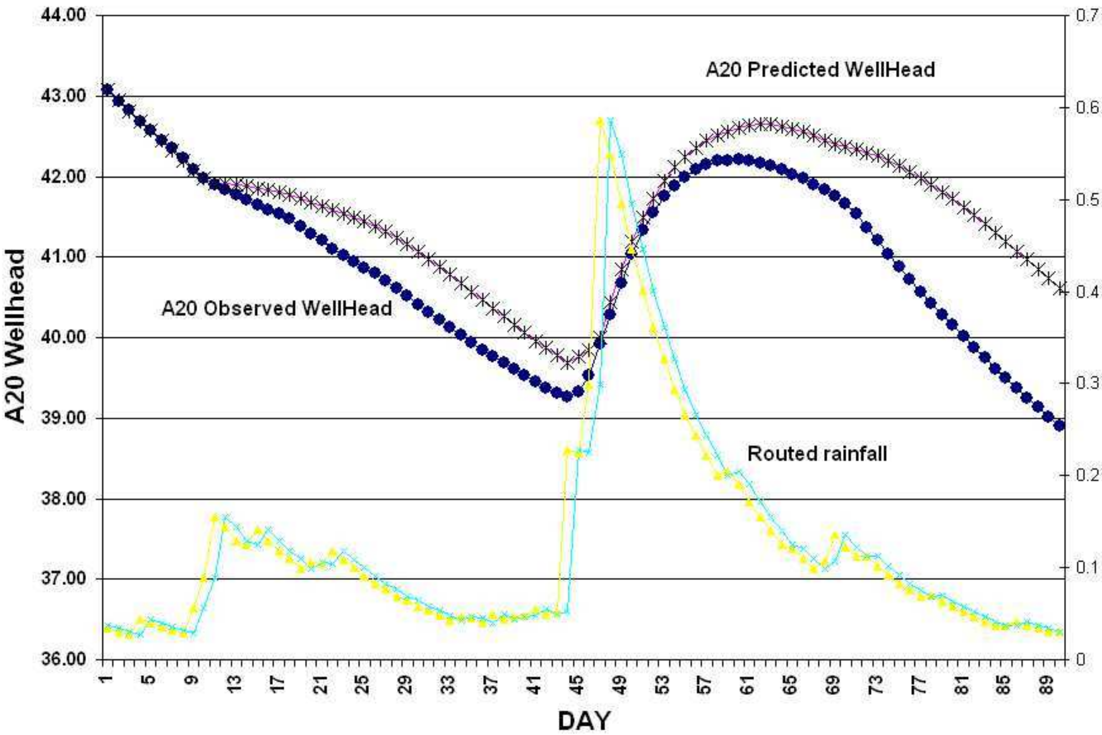

Figure 4. Observed (solid circles) and predicted (cross hatches) A20 wellhead response to an extreme daily rainfall event that occurred on 15 February 1999. Day 1 = January 1, 1999. The rainfall is fed into the well with a delayed response given as the outflow from a hypothetical intervening reservoir.

Principal Findings and Significance

Very accurate predictions of wellhead in the northern Guam lens aquifer can be made from known values of daily rainfall and sea level. Cross correlation values exceeding +.90 can be achieved for the argillaceous A series wells, and exceeding +.75 for the M series wells in the north. All of the predictions were made in hind cast. The high accuracy of these predictions, however, implies that were substantial rainfall and/or sea level anomalies to be known in advance, say through accurate predictions of El Niño, then useful predictions of wellhead could be made.

While in the course of this project, some important findings emerged that have potential value for future research: (1) an abrupt rise of the sea level was noted on Guam beginning during 1998 and continuing through the following decade, and (2) an extreme 24-hour rainfall amount occurred in late June of 2004 while Guam was in an outer *rainband* of Typhoon Tingting.

During 1998, a rapid sea level rise was noted in Guam tide gage readings. Since that year, the sea level on Guam has remained well above its historical stand. This sea level rise also appears in the time series of Guam's wellheads. Substantial erosion occurred along much of Guam's coastline over the past decade, and its cause is debated. There were an unusual number of typhoons during the 1990s, and the sea level rose abruptly after the 1997 El Niño. It is not known what effects a rising sea will have on the flow characteristics of the NGLA. The location of dissolution-widened channels within the limestone is affected by the long-term sea level. A sustained rise in Guam's sea level could have an impact on the properties of Guam's aquifer.

The daily rainfall during the passage of Typhoon Tingting near Guam on 28 June 2004 was over 20 inches for most of the island. This occurred while Guam was in an outer rain band of the typhoon. The center of the typhoon passed well north of Guam. This was the first time that a 20-inch daily rainfall event occurred in anything other than the direct passage of a typhoon eye wall over Guam (e.g., both Chataan and Pongsona yielded 24-hour rainfall in excess of 20 inches across much of Guam). Whereas Tingting produced its extreme 24-hour rainfall through the net accumulation of several hours with rain rates on the order of 2 inches per hour, the same extreme daily rainfall values in Chataan and Pongsona occurred with extraordinary hourly rain rates of 6 or 7 inches per hour within the typhoon eye wall. This is an avenue for further research.