GROUNDWATER MODELING OF THE YANAMAREY AND QUICAYHUANCA PAMPAS, CORDILLERA BLANCA, PERU

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MSC. 1

MASTER’S PROPOSAL

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**INTRODUCTION**

The Cordillera Blanca of Peru is the most extensive and widely studied glaciated mountain range in the tropics (Mark and McKenzie, 2007). During the last glacial recession, glacial melt water formed pro-glacial lakes in areas that were dammed, either by the glacial moraines or by ice dams. These pro-glacial lakes filled with glacial till and fine sediments creating lacustrine plains along the floors of steep sided u-shaped glacial valleys. The accumulation of sediments created an impermeable environment where glacial melt water and precipitation began to collect over the glacial deposits. The buildup of water in addition to the extremely flat topography, led to water tables maintained at or near the land surface and the formation of organic-rich peat soils. In the Peruvian Andes, these flat glacio-lacustrine environments composed of unconsolidated materials and overlain by peat are known as pampas.

Pampas, or the very similar paramos, are found in many South American countries, predominantly in Peru, Brazil, Uruguay and Argentina. Soils in the Peruvian pampas are poorly developed and sparse vegetation (usually the result of overgrazing by livestock) (Mark and Seltzer, 2003) consists of small moss plants, very few trees, grassy prairie and grass steppe, which is commonly known as “Pampa Grass” (Columbia Encyclopedia, 2008). A common feature of each pampa is the presence of one or two glacially fed streams. The largest annual source of water to these streams is glacial melt water, with substantial inputs from rainwater and groundwater (Baraer et al., 2007). These streams are an important water resource, providing water for domestic, agricultural and hydroelectric power in the surrounding communities. However, the current accelerated glacial recession has resulted in great concern regarding regional water availability, and the fate of these glacially sourced streams in particular (Mark and McKenzie, 2007).

In the Yanamarey and Quilcayhuanca pampas (Figure1), patterns of groundwater flow, recharge and residence times are governed by geomorphology and subsurface sedimentology (Robinson et al., 2008). Baraer et al. (2007) used geochemical and isotopic methods to show during the dry season, groundwater is an important component in the hydrological budget and can account for the majority of steam discharge (Baraer et al., 2007). The physical hydrogeologic processes that control this flux of groundwater to streams are not well understood. Baraer et al (In prep) propose that the top layers of a pampa are low a permeability, making them hydrologically isolated from deeper groundwater flow, and a minor component of the net flux of water to the main valley streams. These results suggest that there is a deeper groundwater system, which is primarily responsible for surface water contributions, as opposed to shallow dry season runoff.

Numerical groundwater flow models are used to determine flow patterns, flow direction, water residence times and to determine which hydrogeologic parameters control groundwater flow systems. As a result of the remote locations of the Quilcayhuanca and Yanamarey Pampas, acquiring values for the hydrogeological parameters such as permeability, storativity, porosity, elevation and hydraulic head are difficult. Accessibility and vandalism limit the ability for long term installation of equipment. The numerical groundwater flow model will be used to develop a conceptual model of groundwater flow, recharge and residence times in pampas, which is critical in assessing total water availability during the dry season.
OBJECTIVES

My proposed Master’s research will focus on the Yanamarey and Quilcayhuanca Pampas, Peru. Although the contributions of groundwater to streams in these systems is important (Baraer et al., 2007), the process that controls the movement and residence time of groundwater is poorly understood. My study objectives are to develop a three-dimensional finite-difference groundwater flow model for the Yanamarey and Quilcayhuanca pampas, calibrated to field data, and to develop a large scale three-dimensional finite-difference groundwater flow model for the entire Quilcayhuanca Pampa through scaling of the detailed model.

STUDY AREA

The Cordillera Blanca of the Northern Andes in Peru, are located between 8.5° - 10°S and 76.5° - 77.5°W. The mountain range is approximately 10 Ma and sits on the magmatic Andean arc (Baraer et al., 2009). It is oriented along a northwest-southeast strike, which is controlled by the structural trend of the Andes (Mark and Seltzer, 2005). The Cordillera Blanca is 120 km long, and the glacierized area on the western side discharges to the Pacific Ocean via the Rio Santa (Mark and Seltzer, 2003).

The total glaciated area of the Cordillera Blanca is 631 km² (Suarez et al., 2008). The glaciers are strongly crevassed and thin, without pronounced glacier tongues (Georges, 2004). The Yanamarey glacier is at an elevation between 4600 and 5300 m.a.s.l. and runoff from the glacier flows across the Yanamarey Pampa (2.54 km²), located in the Querococha watershed (62km²) to Lake Querococha, which is a pro-glacial lake that formed in the bedrock after a recent glacier retreat (Mark and Seltzer, 2003). The Pucaranra, Chinchey, Tullparaju, Chopiraju and Cayesh glaciers, at elevations between 5500 and 6500 m.a.s.l., discharge into the Quilcayhuanca River, which flows across the Quilcayhuanca Pampa (3.55 km²), and is located north from the Yanamarey Pampa.

The Yanamarey (9°40’28.174”S, 77°17’23.993”W) and Quilcayhuanca (9°27’52.140”S, 77°22’40.020”W) pampas are both located west of their respective source glaciers. Both study sites are similar with little vegetation and poor soil development. The streams in the pampas are shallow, with depths less than 1 m, and streambeds usually composed of well-rounded rocks, with banks cut by the river comprised of fine clays and silts. The top 10 m of the subsurface is thought to be fine grained sediments and peat deposits, which lie above loosely consolidated glacial outwash gravel (alluvium and till). The bedrock on the western side of the Cordillera Blanca is composed of metamorphosed sedimentary rocks (quartzite and hornfels) (Mark and Seltzer, 2003) and is 80% to 90% batholith with the remainder being isolated areas of tonalite and diorite (McNulty et al., 1998). This lithology of the batholith is granodioritic (Mark and Seltzer, 2003) and characterized by high silicate contents (Baraer et al., 2009).
PRELIMINARY FIELDWORK AND RESULTS

In July 2009 the Yanamarey and Quilcayhuanca pampas were chosen for this study based on their accessibility and representativeness of pampas of the Cordillera Blanca. At Quilcayhuanca an engineer’s level was used to carry out elevation surveys in order to accurately map the water table of the study area. For the Yanamarey Pampa airborne light detections and ranging (LIDAR), a remote sensing method which uses short wavelengths of the electromagnetic spectrum to measure distances from a source to a target, was used in 2008 to survey high resolution topography. An auger was used to drill down to the water table at various locations in both pampas in order to assess the water table. It was found that in both areas, the water table was consistently less than 1m below the surface.

In July 2008, a water table well MW1 (9°27.876 S, 77°22.685 W) was installed in the Quilcayhuanca Pampa. Data from that well will be analyzed and used to calibrate the groundwater model. In July 2009, two more water table wells made from polyvinyl chloride (PVC) were installed in the Quilcayhuanca pampa at MW2 (9°27.937 S, 77°22.672 W) and MW3 (9°27.937 S, 77°22.716 W) to measure the fluctuation of the water table at hourly intervals for one year (Figure 2). Stream elevations for the Yanamarey groundwater flow model were extracted from the LIDAR data that was collected in 2008, and elevations for the Quilcayhuanca groundwater flow model were taken from the elevation surveys that were carried out in July 2009. The water table was plotted on both models and contoured for the Yanamarey and Quilcayhuanca Pampas. At the Yanamarey Pampa there appears to be a topographic divide of the water table between the two streams, likely due to an assumed bedrock high (Figure 3). In Quilcayhuanca there is a convergence of the water table at a low point to the south of the stream.

In July 2006 and 2007, vertical streambed temperature profiles were measured in the northern stream of the Yanamarey Pampa. In July 2006, one temperature sensor profile was installed for one year and in July 2007 two temperature sensor profiles were installed for ten days. The decrease in temperature amplitude with depth between paired sensors were quantified, and using a one dimensional analytical solution to the heat transport and groundwater mass balance equation, vertical groundwater flow velocities were calculated (Hatch et al., 2006). The results showed that at higher elevations the vertical velocity was downward from the streambed to the ground, and at lower elevations further downstream the vertical velocity of water is upward into the stream.

METHODOLOGY AND FUTURE WORK

Fieldwork at the Yanamarey and Quilcayhuanca pampas will occur in July 2010. The current planned field work includes the collection of water table data from wells installed in July 2009, additional water table measurements by drilling with an auger to the water table, installation of piezometers to measure hydraulic head, slug tests to determine hydraulic conductivity, installation of streambed temperature sensors to calculate additional vertical velocities, core samples to determine the subsurface material, and water samples from wells to analyze the groundwater chemistry.
Based on the expected results from the additional data to be collected in July 2010, the groundwater flow systems in the Yanamarey and Quilcayhuanca Pampas will be modeled using MODFLOW, a three-dimensional finite-difference groundwater flow model program developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). Observations from the water table wells, additional water table measurements, and hydraulic head will be used to adjust the model parameters, such as hydraulic conductivity, during calibration. Streambed temperature sensors will be used to further calibrate the model to the vertical flow of water between the stream and the groundwater. Core samples will be used to accurately assign hydraulic conductivity, storativity and effective porosity values. They will also be used in determining the subsurface stratigraphy and will verify the depth of the bedrock, which is currently believed to be at a maximum depth of 24 m with a ‘u-shaped’ bathymetry, typical of glacial valleys. Finally, the groundwater chemistry results will provide additional support for the groundwater models and for to the previous work of Baraer et al. (2009).

Stream and topography elevations for the Yanamarey groundwater flow model will be based on the LIDAR data collected in 2008, and elevations for the Quilcayhuanca model will be taken from the elevation surveys that were carried out in July 2009 and LIDAR data collected in 2008. The elevations will be used to generate the specified head and ground surface that will represent the top boundary of the model. The bottom boundary will be a no flow boundary representing the top of the bedrock.

Once the model is calibrated, changing parameter values to determine which will have the greatest impact on the model results is used to determine the model’s sensitivity. The final groundwater flow models will be used to create a conceptual model of the processes that control the flow of groundwater and the residence time of this groundwater, and will help guide future hydrogeology studies of these regions. The results will help us to better understand how the contributions of groundwater to the greater-pampa hydrological system.

**Time Schedule**

April 2010 – All required course work will be completed
July 2010 – The final fieldwork expedition will be carried out
Fall 2010 – Development and analysis of a groundwater model for the Yanamarey and Quilcayhuanca pampas
Spring 2011 – Writing and submitting thesis
Figure 1 – Yanamarey and Quicayhuanca Pampa study sites in the Cordillera Blanca, Peru
Figure 2 – Quilcayhuanca Study site. Stream elevations were measured with an engineer's level and water table measurements were taken in situ.
Figure 3 – Yanamarey Pampa study site. Stream elevations were taken from the LIDAR data and water table elevations were measured in situ, and tied to the LIDAR data through GPS measurements. The vertical velocities are calculated from vertical temperature profiles in the stream bed. Negative values indicate upward flow and positive values indicated downward flow.
Literature Cited


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