The Subglacial Hydrology of the Laurentide Ice Sheet in Northern New Jersey

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I. Background

During the Last Glacial Maximum (LGM) the laurentide ice sheet covered Northern New Jersey. Previous studies have shown that groundwater velocities and hydraulic gradients were affected by glaciation in the mid-western United States during glaciation (Breemer et al. 2002, Carlson et al. 2007). The problem that I am addressing is whether or not the presence of a subglacial water film would have had an effect on groundwater flow in the New Jersey. To understand the effects of glaciation on the aquifers of New Jersey I used the groundwater modeling software MODFLOW (Harbaugh 2005).

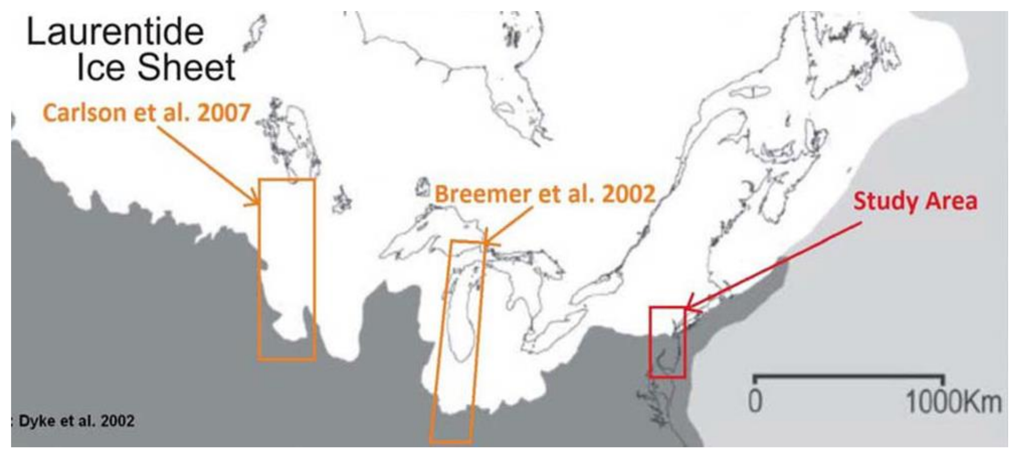

Figure 1: Highlighted in red is the area of study for this thesis and highlighted in orange are the locations of previous studies (Breemer et al. 2002, Carlson et al 2007).

II. Hypotheses

1. The presence of a subglacial water film would create a low hydraulic gradient in New Jersey aquifers near the LGM glacial margin, whereas the absence of a subglacial water film in the same aquifer system would result in a high hydraulic gradient.
2. Thicker overlying ice sheets will produce a steeper hydraulic gradient, but this will be less significant than basal water film.
3. Therefore a low profile ice sheet with a subglacial water film would produce the lowest hydraulic gradient while a thick glacier with no subglacial drainage system would produce the highest hydraulic gradient.

III. Methods

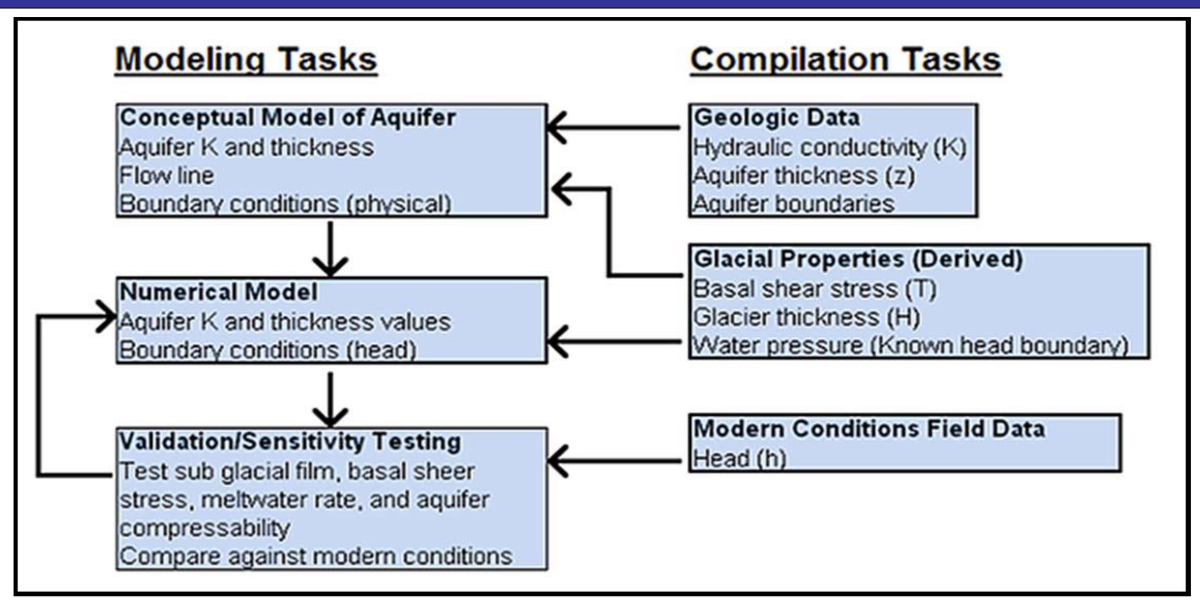

Figure 2: The flow chart outlines the processes involved for modeling subglacial hydrology. On the right are the compilation tasks involving field data, establishment of boundary conditions, and ice sheet reconstruction. To the left are modeling tasks involving the conceptual and numerical models constructed from the compiled data.

IV. Boundary Conditions

The A-A' line in figure 3 represents the central flow line of the glacial lobe. Outlined in red are the terminal moraines for the laurentide ice sheet in New Jersey. This outlines the boundary conditions for the conceptual hydrostratigraphic model by providing the lower boundary conditions, the glacial profile, and the northern and southern boundaries of the model.

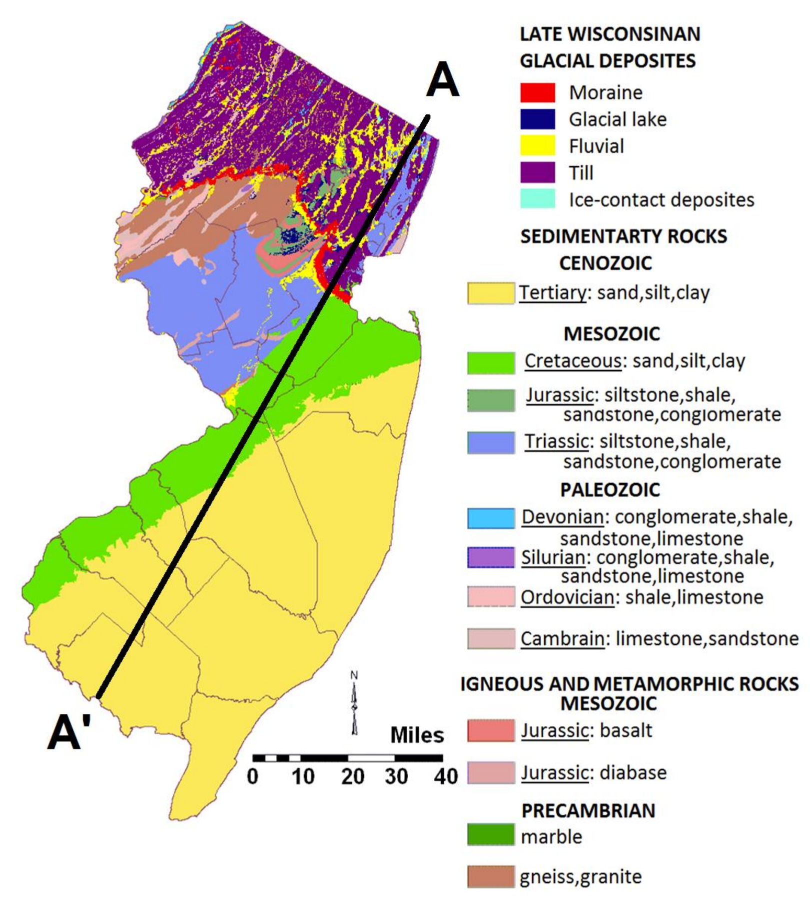

Figure 3: The map is a compilation of geolo-goic and glacial sedim-ent data. Shown in red is the terminal morain of the laurnetide ice sheet which provides the upper boundary condition. The A-A' flow line follows the central flow line of the glacial lobe based on assumptions made by the morphology.

The central flow line of the glacier runs through two distinct geological provinces; the Coastal Plain, and the Piedmont. The Coastal Plain is characterized by permeable Cenozoic sediments and sedimentary rock. The Piedmont consists of relatively impermeable Mesozoic sedimentary and igneous rock.

V. Conceptual Model

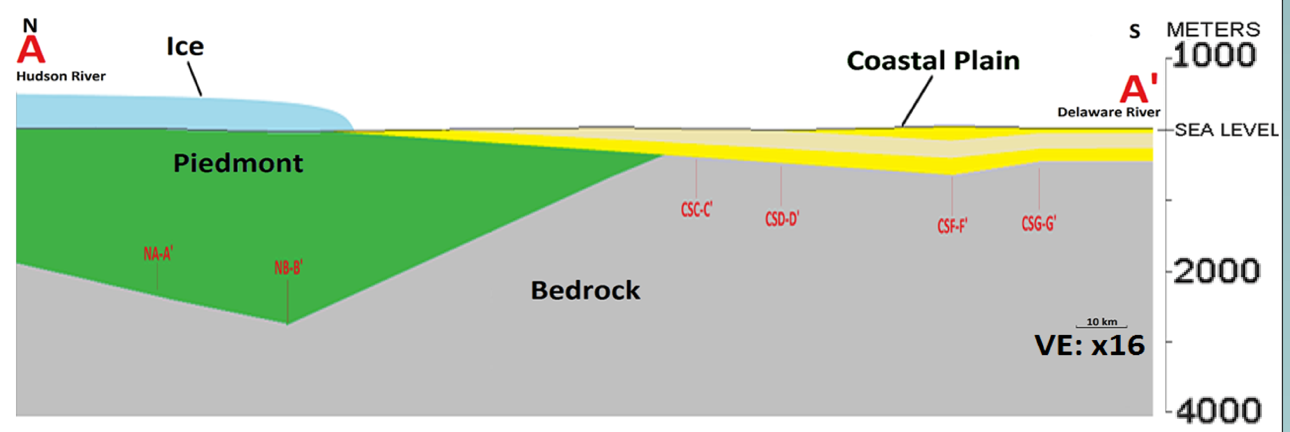

Figure 4: Two-dimensional cross section representing the simplified hydrostratigraphy of New Jersey along the A – A' flowline shown in figure 3. The Coastal Plain is represented as an aquifer-aquitard-aquifer network while the Piedmont is represented as a homogenous aquifer. The bedrock layer is a relatively impermeable boundary. The Hudson and Delaware Rivers form known head boundaries to the Northern and Southern ends respectively.

Acknowledgments

I would like to thank Dr. Karen Prestegaard for her guidance on research, writing, and development of this thesis. I would also like to thank Dr. Richard Winston for his advice and input on my MODFLOW constructed model.

VI. Numerical Model

The table below outlines the variables used for the MODFLOW model. To simulate glacial thickness shear stress values are used to solve the Orowan and Perutz (1949) equation: $H^2 = \frac{2\tau}{\rho_i g}x$ where τ is the basal shear stress (kN m^{-2}), ρ_i is the density of (900 kg m^{-3}), g is acceleration from gravity, and x is the distance from the glacial margin (m). Subglacial water films greater than 7mm result in non-Darcian flow and therefore are not used in this model and basal melt rates between 1 to 7 mm yr^{-1} are used based on values from modern observations.

All MODFLOW model runs are performed as steady state models over the period of one year. To model the hydraulic conductivity of the sub-glacial film, the Romm (1966) fluid in fracture flow equation is used:

$$K = \rho_w gb2 / 12\mu$$

where μ is the viscosity and ρ_w is the density of water at 0 °c.

Variables	Film Thickness (mm)	Basal Shear Stress (kN m^{-2})	Basal Melt Rate (mm yr^{-1})
Series 1			
Trial 1	7 mm	20 kN m^{-2}	1 mm yr^{-1}
Trial 2	7 mm	150 kN m^{-2}	1 mm yr^{-1}
Trial 3	7 mm	20 kN m^{-2}	7 mm yr^{-1}
Trial 4	7 mm	150 kN m^{-2}	7 mm yr^{-1}
Series 2			
Trial 1	0 mm	20 kN m^{-2}	1 mm yr^{-1}
Trial 2	0 mm	150 kN m^{-2}	1 mm yr^{-1}
Trial 3	0 mm	20 kN m^{-2}	7 mm yr^{-1}
Trial 4	0 mm	150 kN m^{-2}	7 mm yr^{-1}

VII. Model Results

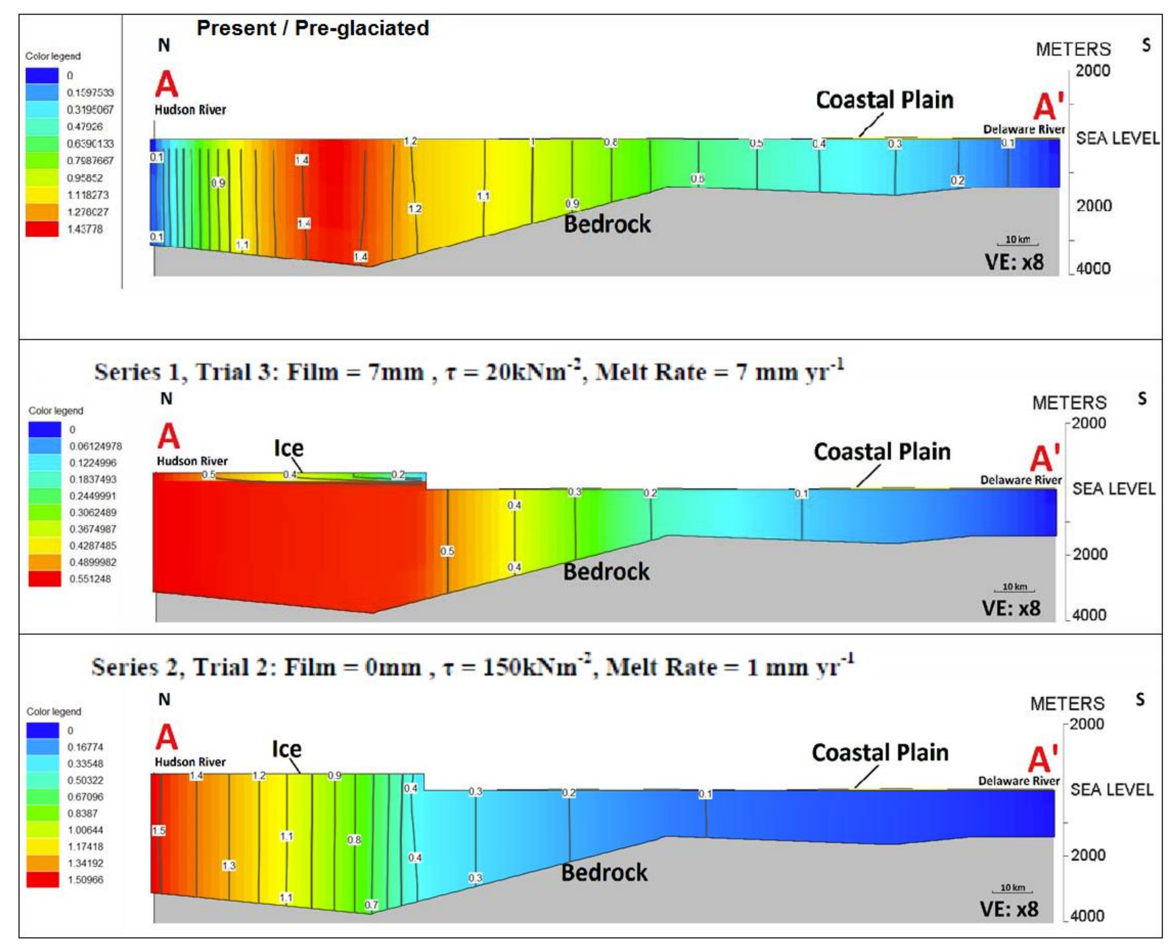

Figure 5: A total of nine models were run. Above are the three most likely models to have existed during critical stages of glaciation. The top model uses the same parameters as the glaciated models except the glaciated layers are removed, the Hudson river boundary is treated as a known head boundary of 0 m and a constant infiltration rate of 0.13 m yr^{-1} for the Piedmont and 0.228 m yr^{-1} for the Coastal Plain.

The middle model would most likely have existed during the melting stages of glaciation since it has a low profile, a high melt rate, and a subglacial water film.

The bottom model would most likely have existed during the LGM since it has a thick profile, a low melt rate, and no subglacial film.

VIII. Conclusion and Discussion

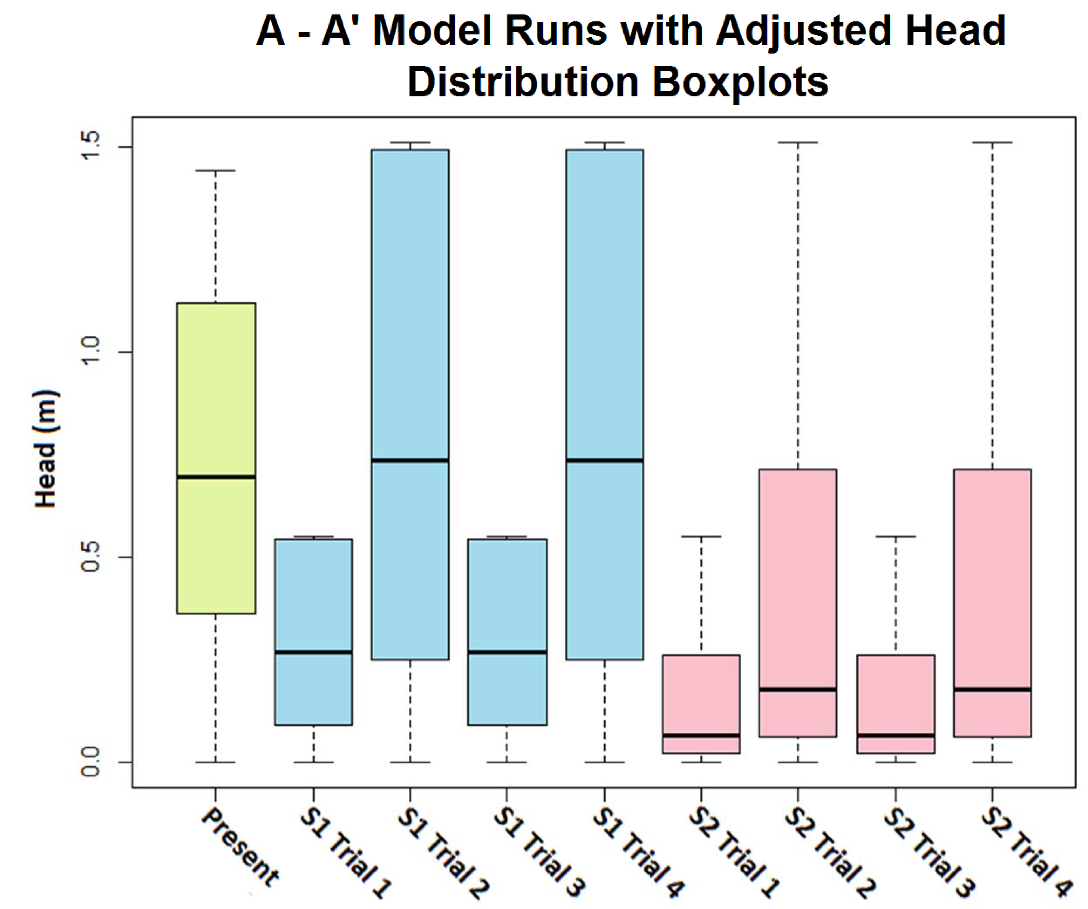

Figure 6: The presence of a subglacial water film decreased the hydraulic gradient and allowed the water pressures to distribute more evenly which supports the first hypothesis. The thickness of the ice sheet does have a greater effect on hydraulic gradient than expected in hypothesis two. This could be because of the relatively short horizontal distance. Basal melt rate had an insignificant role for head distribution for the glaciated systems. However, non-glaciated systems where heavily influenced by infiltration rates.

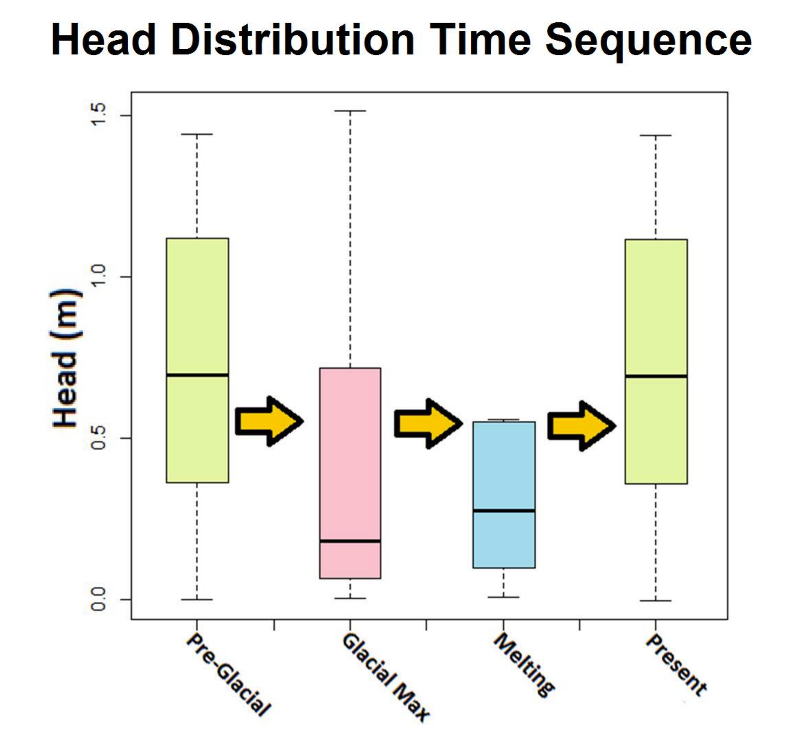

Figure 7: The boxplot above plots the results from figure 5 are placed in a time series resembling pre-glacial conditions (Present), glacial maximum conditions (Series 2 Trial 2), melting conditions (Series 1 Trial 3), and present day conditions (Present). However, present day conditions may be altered by glaciated conditions where transient flow models would be required to model such a response.

IX. References

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