Modelling the Influence of Subsurface Geology on Northern Peatland Hydrology

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INTRODUCTION

Peatlands are complex wetlands that play an important role in global carbon cycling as both carbon sinks and sources; they contain over one third of all global soil carbon but cover <3% of all land surfaces. The hydrology of a peatland exerts a significant control on overall carbon cycling as the position of the water table directly impacts carbon sequestration while circulation within the peat basin will determine nutrient availability.

Traditionally, ombrotrophic bogs, a type of peatland, are defined to be hydrologically separate from the regional groundwater system and receive all of their water inputs from precipitation. However, two decades of hydro-geophysical investigations of northern peatlands in Maine, USA have identified the presence of buried eskers, a type of glacial deposit, at the base of certain ombrotrophic bogs. These studies hypothesized that eskers drive vertical flow within the bog and may act as a primary control on the hydrology of the system due to the pressure differential caused by the change in hydraulic conductivity.

The objective of this study was to develop a groundwater model of Caribou Bog, near Bangor, ME, USA to show the role of these buried eskers on the hydrology of an ombrotrophic bog.

METHODS

Model development was performed using USGS MODFLOW-6 utilizing the FloPy python package to create and run the models. Digital elevation maps, national hydrography data, soil-water balance estimates, surficial geology maps, and evapotranspiration rates were all obtained using publicly available datasets (USGS, MGS, Copernicus). Peat basin stratigraphy and the location of esker beads within the bog were determined using ground-penetrating radar (GPR) and core sampling. Conductivity values (Table 1) were determined using established literature values and from previous work in Caribou Bog. A 10x vertical anisotropy was included to account for material heterogeneity.

A 7-layer, 100x100 grid regional model covering an 18.5 km x 23km area was first created to establish watershed boundaries and initial head values. The unsaturated zone package and evapotranspiration package were used to simulate real-world climatic conditions during three season (spring, summer, and fall). Hand-measured hydraulic head values from wells in Caribou Bog were used to manually calibrate the model. The Local Grid Refinement package was then used to refine the model over a single unit of Caribou Bog. This grid refinement increased the gridding three-fold in the x and y directions while the vertical layering was increased to 11 layers to create a 45, 48, 11 model covering a 2.5 km x 3.5km area.

RESULTS & FUTURE WORK

The presence of buried eskers within the model show two main(e) results:

1. Buried eskers exert **an influence on the hydrology of an ombrotrophic bog**, particularly in the vertical direction.
2. They act as a **linkage to the underlying, regional aquifer system.**

These results show that ombrotrophic bogs that formed over previously glaciated areas may not be as isolated from the groundwater system as traditionally defined. The modelling results in particular show water upwelling from below the peat basin up toward the surface of the bog which may have implications on pool formation, vegetation, and carbon flux at these locations.

Future work to better understand these systems will include further calibration of the model using more advanced parameter estimation tools as well as developing models of other study sites with varying underlying geology. Additionally, work to measure the carbon flux of areas around the bog will be conducted to determine if there is a spatio-temporal relationship between the buried eskers and carbon emissions.

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STUDY AREA

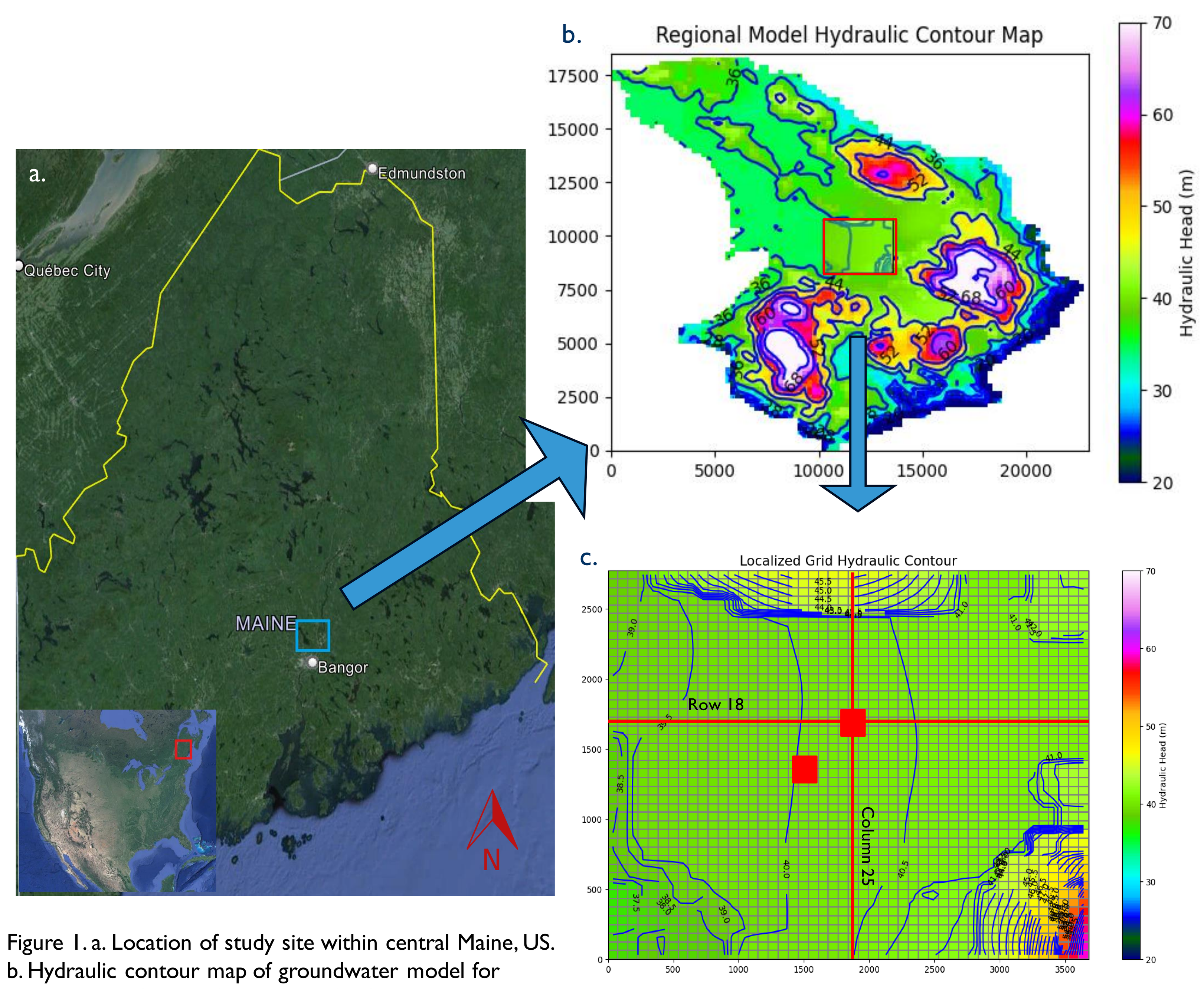

Figure 1. a. Location of study site within central Maine, US. b. Hydraulic contour map of groundwater model for watershed scale model. Location of refined grid area within the model encompassing one unit of Caribou Bog is outlined in red. c. Hydraulic contour map of locally refined model over area of interest. Location of cross-sections for subsequent figures and buried esker beads are in red.

Material	Peat (upper)	Peat (mid)	Peat (deep)	Clay	Till (ablation)	Till (lodgement)	Bedrock	Esker	ET	Infiltration Rate
Hydraulic Conductivity (m/day)	8.64	0.864	0.08	0.0001	0.17	0.017	0.0000008	8.6	0.0032	0.000035

Table 1. Conductivity values of all materials used within the model in meters/day. Evapotranspiration (ET) and Infiltration rates are also in meters/day and show the value used during the summer time-step.

MODELLING RESULTS

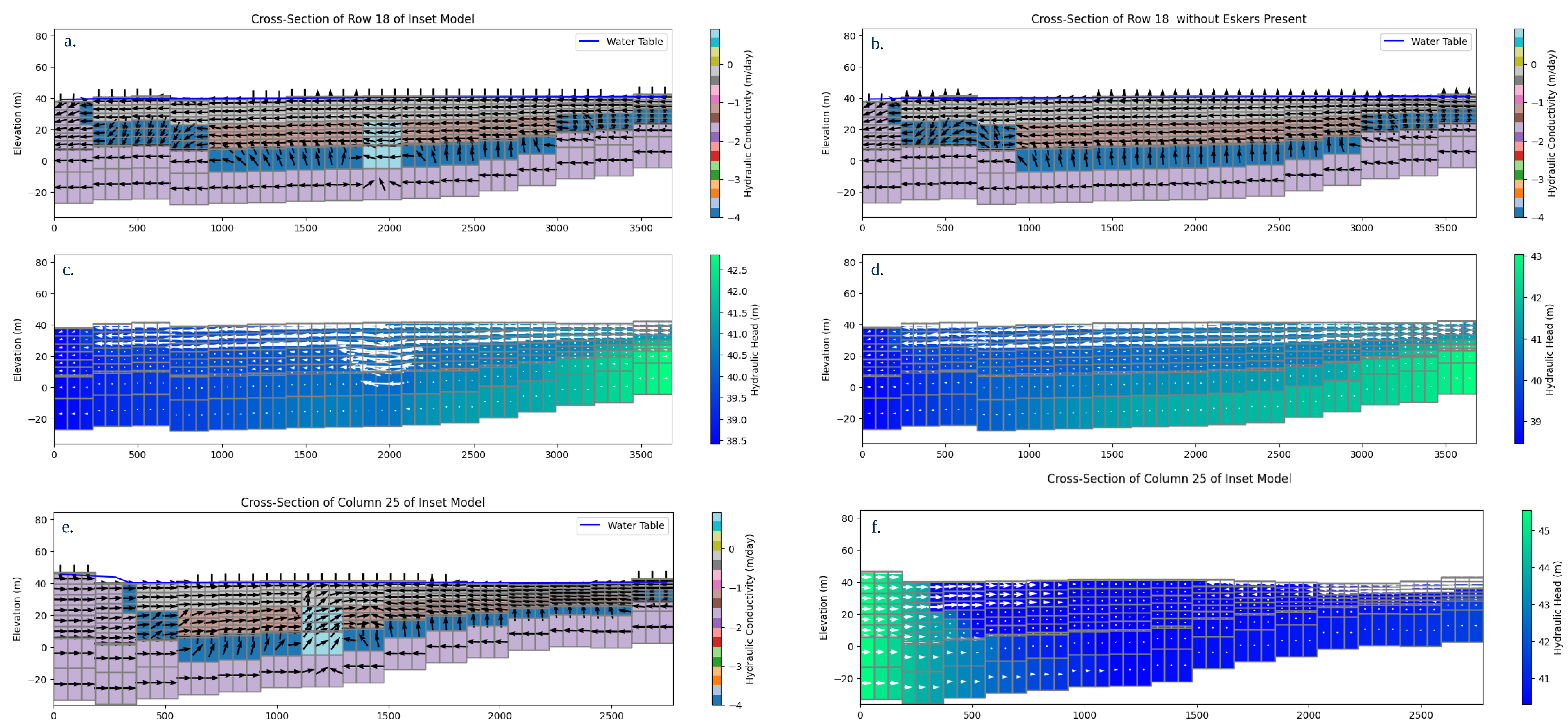

Figure 2. Cross-sectional results of row 18 and 25 within localized grid. a. and b. show the hydraulic conductivity values of the peat basin with and without an esker. Light blue area in center depicts an esker, darker blue layer is the clay. The gray and beige are the peat layers while the purple is the underlying till. Specific discharge is normalized in these two graphs to show direction of flow. c. and d. show the same cross-section but show the hydraulic heads and size of the arrows now depict relative magnitude of discharge and direction. Graphs e. and f. show the same as a. and c. but along a vertical cross-section. The graphs with the esker show a clear up-welling from the till (i.e. aquifer) into the peat basin while the graphs without the esker do not show any up-flow. The magnitude of flow is stronger in c. rather than f. as that is the direction of the hydraulic gradient seen in Figure 1c., Additionally, the flow within the upper layers of the peat in both of the model with and without the esker show flow moving with that same hydraulic gradient.

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