HYDROGEOLOGIC SIMULATION OF GREAT MARSH, CHESTER COUNTY, PENNSYLVANIA USING GIS AND MODFLOW 6 TO UNDERSTAND THE WETLAND'S PROLONGED EXISTENCE

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ABSTRACT

Great Marsh is a 1,011 ha wetland located in the Piedmont Upland Section of Chester County, Pennsylvania. Great Marsh is significant for its preservation of 16.4 ka tundra pollen, documenting climate change from a Pleistocene periglacial tundra environment into an upland deciduous wetland through the Holocene. Understanding the hydrogeologic setting of Great Marsh is fundamental for interpreting hydrologic conditions of the geologic past and predicting the hydraulic influence of future climatic conditions.

A groundwater flow model was constructed using MODFLOW 6 to simulate the Great Marsh Watershed. The watershed has an area of 2,220 ha, drained by Marsh Creek. Model topography was established using a LiDAR digital elevation model (DEM) with 10 m spacing. Geologic units include graphitic felsic gneiss and quartz monzonite felsic gneiss of the Mesoproterozoic Baltimore Gneiss Formation, saprolite, periglacial colluvium, and Pleistocene and Holocene alluvium. A precipitation recharge rate of 0.302 m/yr was used in the model, determined from regional hydrograph baseflow separation. Model discharge was simulated using the MODFLOW river package based on stream and wetland locations draped over the DEM using GIS. For the purposes of this investigation, the model simulation was performed under quasi steady-state conditions.

Model-simulated hydraulic heads closely matched the locations of mapped wetlands. The model confirmed previous studies that concluded the wetlands resulted from a lithologic transition from fractured graphitic gneiss to weathering-resistant quartz monzonite felsic gneiss near the base of the watershed. Fractures, faults, and lithologic discontinuities indicated by lineation analysis using aerial image photogrammetry and LiDAR hillshade models may explain the location of springs and preferential groundwater discharge locations within the watershed. Furthermore, we conclude that the structural geometry of the Great Marsh Watershed produces a climate-resilient wetland that is relatively insensitive to changes in recharge, which suggests that future climate change is unlikely to significantly alter the hydrologic conditions of Great Marsh.

INTRODUCTION

Great Marsh is a long-standing wetland in Chester County, Pennsylvania. Figure 1 features images of the marsh taken by Lori Moore. Figure 7 features the wetland's shape superimposed over an aerial image of the marsh accompanied by figure 8 which is an aerial Google Maps image of the marsh. Great Marsh is located in the Welsh Mountain Anticline and includes two Proterozoic (2500 to 538.8 Mya) formations: the Pickering Gneiss and Quartz Monzonite of the Granulite facies. The gneiss was been eroded into gently rolling beds (Bricker and Moss 1958) surrounded on three sides by monzonite. The monzonite, which is quartz bearing, is less susceptible to erosion than the gneiss, forming a geologic chokepoint at the base of the watershed. The gneiss is medium grained and light to dark gray in color. It bears a high percentage of graphite. The most common mineral in the gneiss is quartz, with accessories of biotite, magnetite, hornblende, and garnet. The monzonite is medium grained and is light gray to black in color and is high in feldspar with accessories of hornblende, biotite, magnetite, and garnet. Other notable units are saprolite, periglacial colluvium, and Pleistocene and Holocene alluvium. Figures 2 and 3 feature visualized elevation data for the watershed of the marsh.

Great Marsh is part of the Brandywine Creek East Branch watershed with output into the Delaware River. The pour point (lowest part of the watershed) used for the groundwater flow model of Great Marsh is the USGS 01480675 Marsh Creek near Glennmoore, PA gauging station. The main stream channel is Marsh Creek, which drains into Marsh Creek Reservoir.

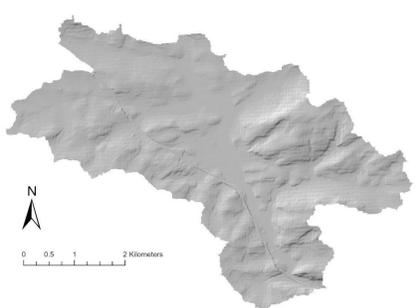**Figure 1.** Photography of Great Marsh (Lori Moore, 2023)

Figure 2. Hillshade made using digital elevation model from USGS DEM data.

Legend
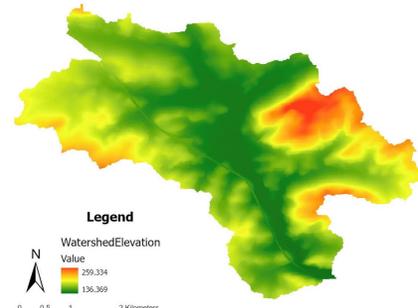WatershedElevation
Value
259.334
136.369

Figure 3. Colorized digital elevation model made using USGS DEM data.

METHODS

Groundwater flow modeling was conducted using Groundwater Vistas (Rumbaugh, 2004) and MODFLOW 6 (Langevin et al. 2017) to evaluate hydrologic behavior of the marsh. Stream discharge data and LIDAR imagery were used to calibrate the model and validate results. GIS software, specifically ArcGIS Pro and QGIS were used to produce shapefiles of elevation, geology, hydrologic features, and other watershed information. Model discharge was simulated using the MODFLOW river package based on stream locations draped over the digital elevation model made using GIS. This model simulation was performed over quasi steady-state conditions.

4 layers were made in the model with 100-meter grid spacing. Recharge was taken from the USGS gauging station data and was 0.001491m/day (Wolock 2003, Reese & Risser 2010). Hydraulic conductivities (K) used are as follows: gneiss: 0.2 m/day, alluvium: 10 m/day, and saprolite 0.2 m/day (Low et al. 2002) . Elevation throughout the model ranges from 130-250 meters. The boundary condition of the model, Marsh Creek, was input as a river.

RESULTS

Current Recharge (0.001491 m/day)

0.1x Recharge (0.0001491 m/day)
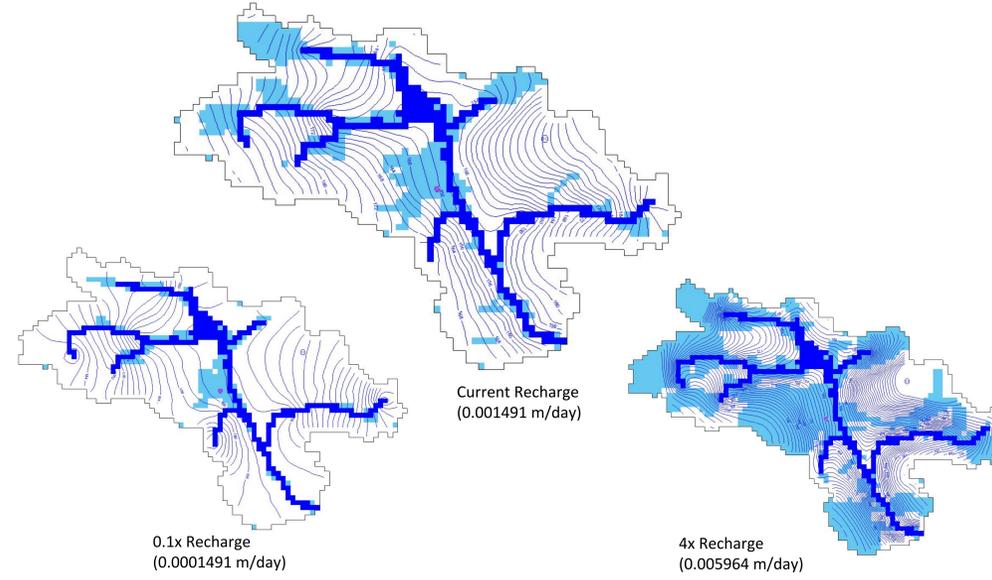
4x Recharge (0.005964 m/day)

Figure 4. Hydraulic head and flooded cell maps of the Great Marsh watershed showing 0.1x the current recharge of the watershed, the current recharge, and 4x the current recharge.
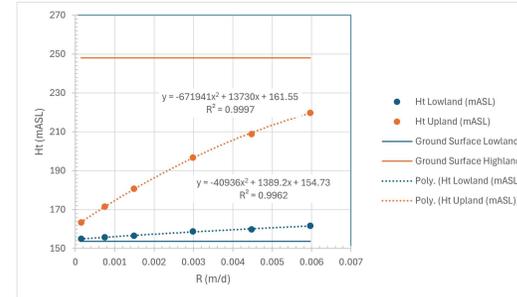

$y = -671941x^2 + 13730x + 161.55$
$R^2 = 0.9997$

$y = -40936x^2 + 1389.2x + 154.73$
$R^2 = 0.9962$

Ht Lowland (mASL)
Ht Upland (mASL)
Ground Surface Lowland
Ground Surface Highland
Poly. (Ht Lowland (mASL))
Poly. (Ht Upland (mASL))

Figure 5. Sensitivity analysis results produced by running model at different recharge rates plotted on chart with ground surface level for reference
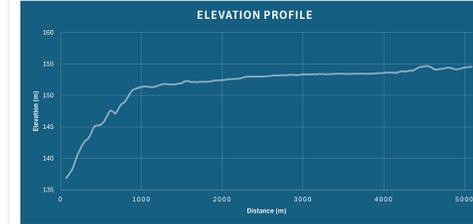

ELEVATION PROFILE

Figure 6. Elevation profile of stream along the watershed made using exploratory 3D analysis tools in ArcGIS Pro.

Figure 4 shows modelling results of running MODFLOW 6 and changing recharge values to compare location and number of flooded cells within the watershed. The middle model, labelled "today's recharge" shows locations where the surface is currently flooded. Hydraulic heads are in the 156-180 range. Increasing recharge increases flooded cells, and while decreasing recharge does lessen flooded cells, even at 0.1x today's recharge the system does not dewater.

Figure 5 features a plotted sensitivity analysis done with two hypothetical wells. One well was placed in the upland area and the other in the lowland. The axes are Hydraulic head on the Y axis and recharge on the X axis. There is also a polynomial trendline to show a possible relationship between hydraulic head and recharge.

Figure 6 shows the profile of the stream along the length of the watershed, showing a knickpoint at the base of the watershed. The elevation of the stream bed ranges from 135-155 meters over a ~5000 meter distance.

Figure 7. Watershed boundary overlaid in ARCGIS onto an aerial map of the marsh.

Figure 8. Watershed top-down view created with Google Maps.

DISCUSSION

Model results support previous studies that concluded the wetlands resulted from a lithologic transition from fractured graphitic gneiss to weathering resistant quartz monzonite near the base of the watershed. Comparing the model results to the geology and stream profile affirm that the difference in bedrock materials are a key cause of Great Marsh's existence.

The results of the sensitivity analysis suggest that the structural geometry of the Great Marsh watershed produces a climate resilient wetland that is relatively insensitive to changes in recharge. Even in a major climate change event where recharge drops to 0.1x what it is today, the marsh does not dewater. This means that future climate change is unlikely to significantly alter hydrologic conditions of the marsh. The upland is more sensitive to a drop in recharge than the lowland, but the lowland ground surface remains below the water table.

Figure 9 features a map of the geometry of the marsh for reference. The gneiss has weathered more readily than the monzonite, leaving a raised lip at the edges of the watershed. This effect is much like a bathtub, keeping the water inside the watershed. The topographic map in figure 10 shows the same phenomenon with a more 3-dimensional perspective.
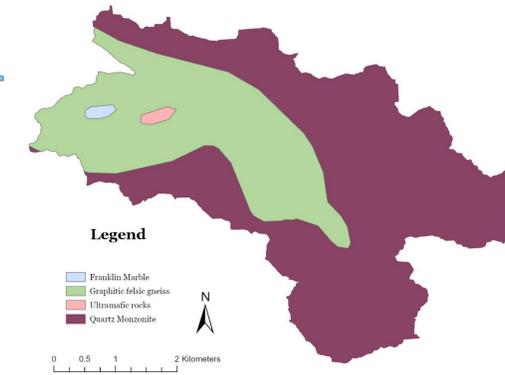

Legend
Franklin Marble
Graphitic felsic gneiss
Ultramafic rocks
Quartz Monzonite

Figure 9. Geologic Map of Great Marsh showing the orientation of the Gneiss surrounded by Monzonite
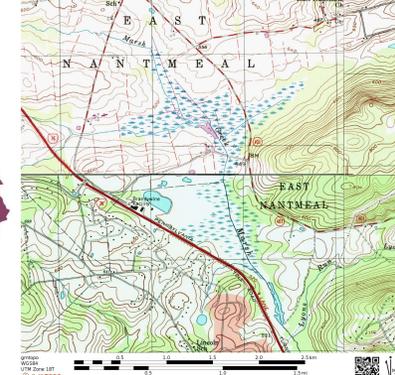

Figure 10. Scanned topographic map of Great Marsh

CONCLUSIONS

- According to the model, changes in recharge, aside from freezing the water (as it was in the Pleistocene) will not completely dewater the marsh
- Marsh is likely incredibly resilient to climate change related changes in precipitation
- Geometry of the geology is likely what is keeping water in the system
- Upland areas are more sensitive to changes in recharge than lowland areas
- Sensitivity analysis shows relationship between hydraulic head and recharge

ACKNOWLEDGEMENTS

GREAT MARSH INSTITUTE

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