An attempt to unveil aquifer response to glaciations using residential water-well data from a partially glaciated county in Ohio

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Abstract

Groundwater flows through interconnected pore spaces. The occurrence and rate of groundwater movement depend upon the storativity and transmissivity of the aquifer. External stresses such as tectonics, glaciation, and hydraulic fracturing can influence porosity and permeability of an aquifer, thus changing aquifer parameters such as hydraulic conductivity and storativity. The scope of this research were to study the variations in the values of aquifer parameters due to cyclic loading and unloading, and compare hydraulic conductivity of the aquifer under glaciated and non-glaciated regions
Data were obtained from public water wells archived at the Division of Soil and Resources (ODNR) that consist information pertaining to well location, well construction details, well production test, and rudimentary lithologic description. We observed a significantly higher hydraulic conductivity for the aquifer in glaciated than that for unglaciated portion of the county which can impact the pumping from wells. This finding is significantly important to agriculture, industry, or public water suppliers who depend on groundwater for their operations and services.

Introduction

The occurrence and rate of groundwater movement depend upon the storativity and transmissivity of the aquifer. External stresses such as tectonics, glaciation, and hydraulic fracturing can influence porosity and permeability of an aquifer, thus changing aquifer parameters such as hydraulic conductivity and storativity.

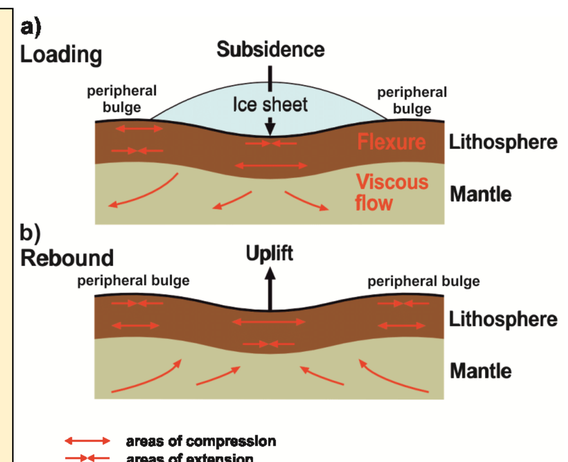


Figure 1. A conceptual diagram of glacial loading and unloading and its impact on underlying rocks

Studies have shown a decrease in hydraulic conductivity with increase in vertical effective stress in a granular aquifer (Bredeheft et al., 1983). Similarly, an increase in thickness of overburden decreases fracture permeability (Davidson et al., 1982). The relationship between external stress and aquifer characteristic is complex and affected by rock type (Davidson et al., 1982), fracture orientation (Gale, 1982), and regional tectonics history (Milnes et al., 1998). We were interested in unveiling whether glacial loading and unloading were effective to change characteristics of the sandstone aquifer lying within Holmes County, Ohio. The scopes of this research were to (i) study the variations in the values of aquifer parameters due to cyclic loading and unloading, and (ii) compare hydraulic conductivity of the aquifer under glaciated and non-glaciated regions. We hypothesized that glacial loading and unloading has impacted the sandstone aquifers in Holmes County, specifically the glaciated wells which will have a higher hydraulic conductivity due to the development of secondary porosity.

Data Collection & Analysis

The study area is located in Holmes County, Ohio which have wells dispersed across townships. Glaciated regions occupied the Northern portion of Holmes County, while the Unglaciated regions was on the Southern portion, this divide is visualized with a glacial extent line (Figure 2).

Data were obtained from 691 public water wells archived at the Division of Soil and Resources (ODNR) that consisted information pertaining to well location, well pumping duration, aquifer depth, and rudimentary lithologic description (Figure 3). Data was processed and analyzed in MS EXCEL (Figure 4).

ArcMap was used to for the interpolation of hydraulic conductivity of sandstone aquifer to map the distribution of hydraulic conductivity over Holmes County (Figure 5).

Results

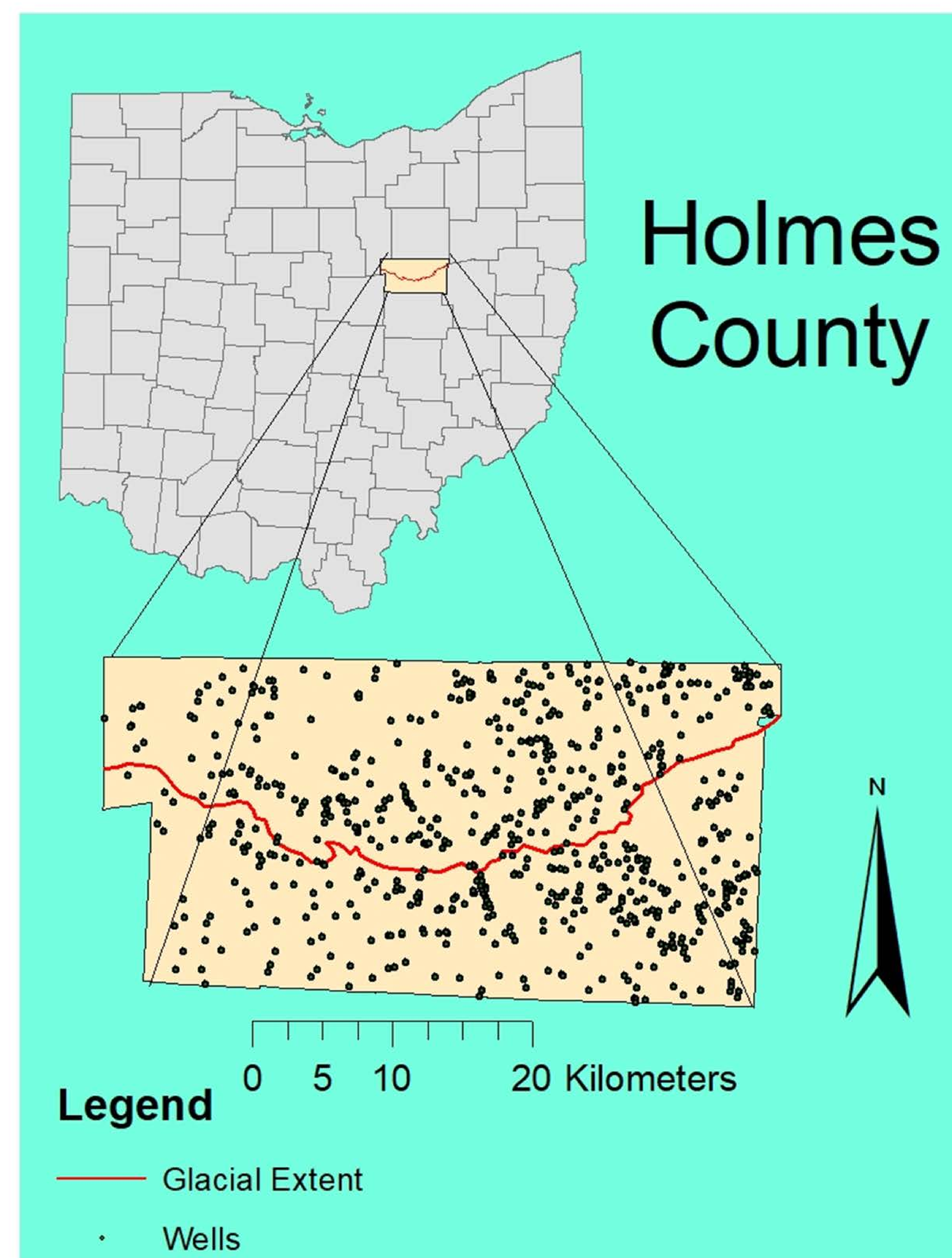
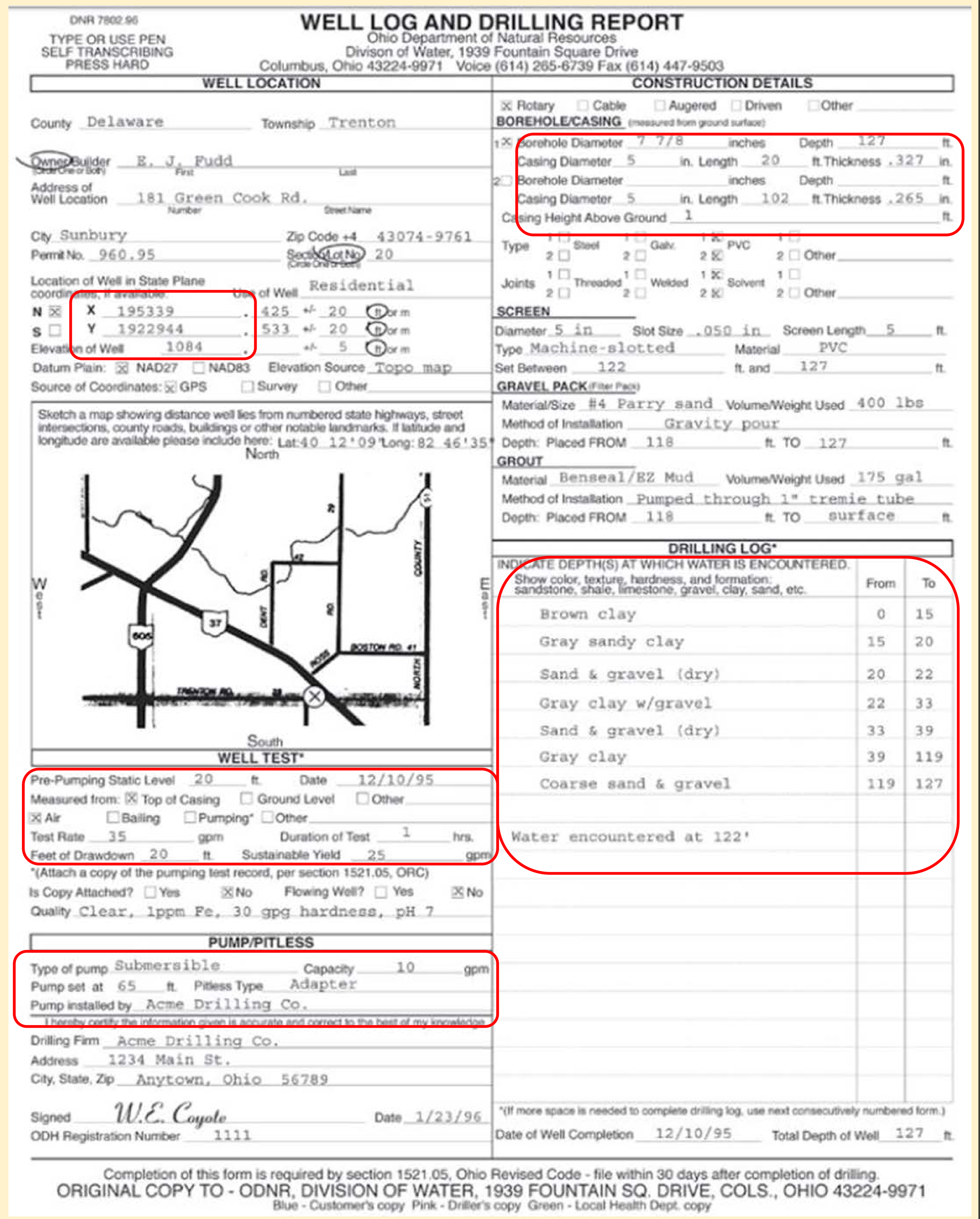


Figure 2. Study may show the glacial extent (red solid line) and distribution of wells in glaciated (northern) and unglaciated (southern) regions of Holmes County, Ohio.



DNR 7802.96
TYPE OR USE PEN
SELF TRANSCRIBING
PRESS HARD

WELL LOG AND DRILLING REPORT
Ohio Department of Natural Resources
Divison of Water, 1939 Fountain Square Drive
Columbus, Ohio 43224-9971 Voice (614) 265-6739 Fax (614) 447-9503

WELL LOCATION

County Delaware Township Trenton
Owner/Builder E. J. Fudd
Address of Well Location 181 Green Cook Rd.
City Sunbury Zip Code +4 43074-9761
Permit No. 960.95 Section/Lot No. 20
Location of Well in State Plane coordinates, if available: Use of Well Residential
N [X] X 195339 . 425 +/- 20 ft or m
S [ ] Y 1922944 . 533 +/- 20 ft or m
Elevation of Well 1084 . +/- 5 ft or m
Datum Plain: [X] NAD27 [ ] NAD83 Elevation Source Topo map
Source of Coordinates: [X] GPS [ ] Survey [ ] Other

Sketch a map showing distance well lies from numbered state highways, street intersections, county roads, buildings or other notable landmarks. If latitude and longitude are available please include here: Lat:40 12'09" Long: 82 46'35"

CONSTRUCTION DETAILS

[X] Rotary [ ] Cable [ ] Augered [ ] Driven [ ] Other

BOREHOLE/CASING (measured from ground surface)
1 [X] Borehole Diameter 7 7/8 inches Depth 127 ft.
Casing Diameter 5 in. Length 20 ft. Thickness .327 in.
2 [ ] Borehole Diameter inches Depth ft.
Casing Diameter 5 in. Length 102 ft. Thickness .265 in.
Casing Height Above Ground 1 ft.
Type: Steel, Galv., PVC [X], Other
Joints: Threaded, Welded, Solvent [X], Other

SCREEN
Diameter 5 in Slot Size .050 in Screen Length 5 ft.
Type Machine-slotted Material PVC
Set Between 122 ft. and 127 ft.

GRAVEL PACK (Filter Pack)
Material/Size #4 Parry sand Volume/Weight Used 400 lbs
Method of Installation Gravity pour
Depth: Placed FROM 118 ft. TO 127 ft.

GROUT
Material Benseal/EZ Mud Volume/Weight Used 175 gal
Method of Installation Pumped through 1" tremie tube
Depth: Placed FROM 118 ft. TO surface ft.

DRILLING LOG*

INDICATE DEPTH(S) AT WHICH WATER IS ENCOUNTERED.

Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand, etc.	From	To
Brown clay	0	15
Gray sandy clay	15	20
Sand & gravel (dry)	20	22
Gray clay w/gravel	22	33
Sand & gravel (dry)	33	39
Gray clay	39	119
Coarse sand & gravel	119	127

Water encountered at 122'

WELL TEST*

Pre-Pumping Static Level 20 ft. Date 12/10/95
Measured from: [X] Top of Casing [ ] Ground Level [ ] Other
[X] Air [ ] Bailing [ ] Pumping* [ ] Other
Test Rate 35 gpm Duration of Test 1 hrs.
Feet of Drawdown 20 ft. Sustainable Yield 25 gpm
*(Attach a copy of the pumping test record, per section 1521.05, ORC)
Is Copy Attached? [ ] Yes [X] No Flowing Well? [ ] Yes [X] No
Quality Clear, 1ppm Fe, 30 gpg hardness, pH 7

PUMP/PITLESS

Type of pump Submersible Capacity 10 gpm
Pump set at 65 ft. Pitless Type Adapter
Pump installed by Acme Drilling Co.

I hereby certify the information given is accurate and correct to the best of my knowledge.
Drilling Firm Acme Drilling Co.
Address 1234 Main St.
City, State, Zip Anytown, Ohio 56789
Signed W.E. Coyote Date 1/23/96
ODH Registration Number 1111

*(If more space is needed to complete drilling log, use next consecutively numbered form.)
Date of Well Completion 12/10/95 Total Depth of Well 127 ft.

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.
ORIGINAL COPY TO - ODNR, DIVISION OF WATER, 1939 FOUNTAIN SQ. DRIVE, COLS., OHIO 43224-9971
Blue - Customer's copy Pink - Driller's copy Green - Local Health Dept. copy

Figure 3. A sample well logs highlighting location, well test, construction of wells, and drilling log that goes into the calculation of hydraulic conductivity of the aquifer.

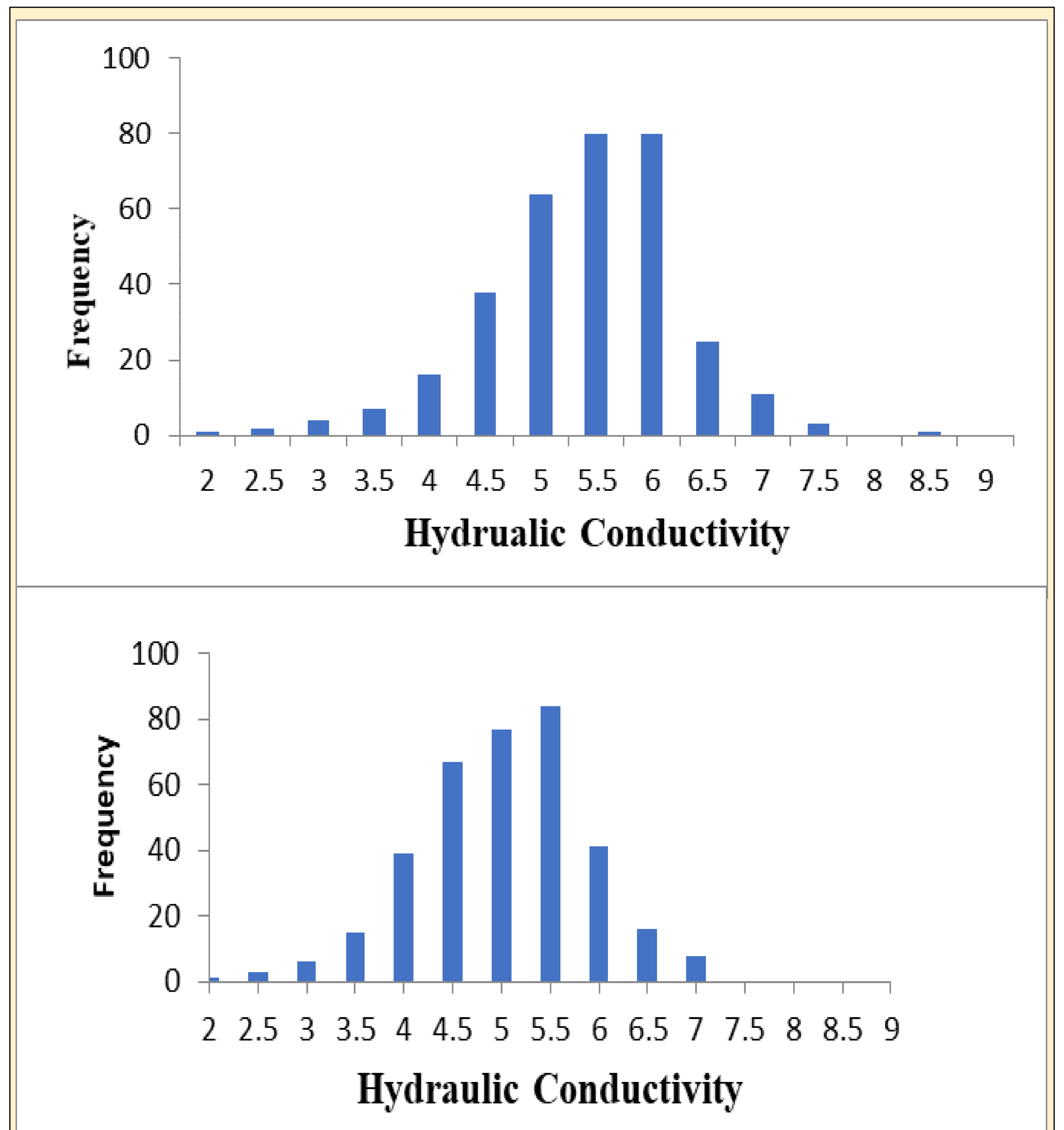


Figure 4. Histogram showing the distribution of hydraulic conductivity of the sandstone aquifer for unglaciated (top) and glaciated (bottom) region.
The K values are log transformed. The lower K value refers to the higher hydraulic conductivity.

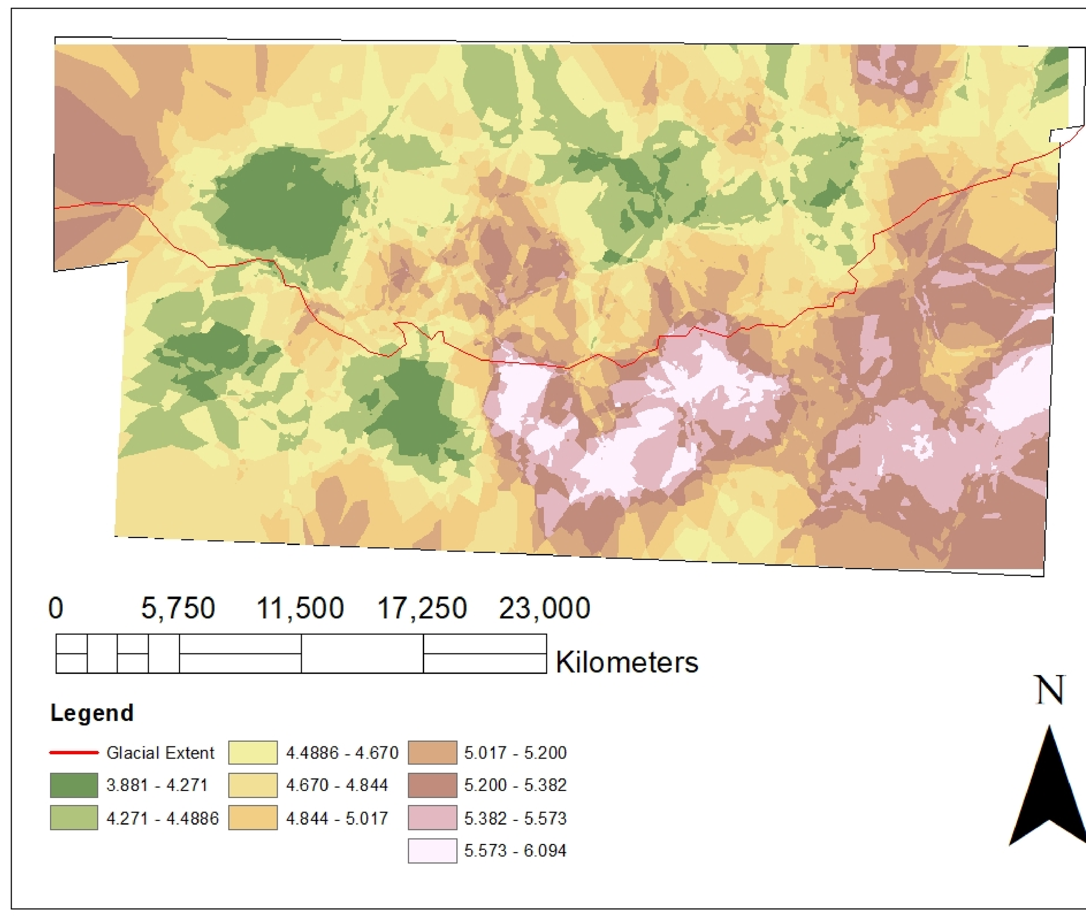


Figure 5. The distribution of the hydraulic conductivity of sandstone aquifer in the glaciated and unglaciated regions of Holmes County, OH.

Table 1. Statistical analysis of hydraulic conductivity values for glaciated and unglaciated regions of Holmes County, OH.

Statistics	Glaciated	Unglaciated
Count	358	333
Mean	4.7	5.3
Median	4.8	5.3
St dev	0.85	0.87
Skewness	-0.29	-0.48

Discussion

The hydraulic conductivity of sandstone in general ranges from 3.00×10^{-10} m/s (9.5) to 6.00×10^{-6} m/s (5.22) (Domenico and Schwartz, 1970). The mean hydraulic conductivity of the unglaciated region matched with the maximum hydraulic conductivity of the sandstone, in general, reflecting the hydraulic conductivity of the unglaciated region is responsible mainly due to the existence of primary porosity, while the hydraulic conductivity of the glaciated region is significantly higher than the unglaciated region which suggests that the glacial loading and unloading had significantly improved aquifer characteristic with respect to the secondary porosity. The difference in the hydraulic conductivity sandstone in Holmes County compared to general sandstone is evident to the fact that the release from pressure by the glacier creates cracks in the sandstone and impacted the hydraulic conductivity.

The mean hydraulic conductivity value of the aquifer in the glaciated region was lower than the median indicating that more than 50% of the wells had higher k values than the mean pointing higher hydraulic conductivity. Furthermore, the skewness for glaciated region is more negative than that for the unglaciated region which is another evidence of the impact of glacial loading and unloading.

These findings indicate that the wells in the glaciated region of Holmes County is more productive than the unglaciated region although areas with similar geology.

Conclusion

The results indicate glacial loading and unloading on the sandstone aquifers increased hydraulic conductivity for the wells located on the glaciated region in Holmes County. Aquifers in this region were impacted by glaciers increasing hydraulic conductivity that has huge implications for groundwater recharge, storage, and withdrawal for future usage. Overall, it is a positive measure towards sustainable development of groundwater in the region.

Future work

Aquifer parameters had changed due to cyclic loading and unloading under glaciated and non-glaciated regions. To claim this as fact, this study can be done on similar geographical regions with similar geology to yield similar results. More specifically, it is interesting to see if there is any relationship (qualitative/quantitative) between the thickness of glaciers and the hydraulic conductivity.

References

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Domenico PA, Schwartz FW (1970) Physical and chemical hydrogeology. Wiley, New York, 825 pp

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Figure 5. Schematic illustration of the loading and unloading effects... 2020. *ResearchGate*. https://www.researchgate.net/figure/Schematic-illustration-of-the-loading-and-unloading-effects-on-the-crust-lithosphere-and_fig3_274735469 (last accessed 15 May 2020).

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Acknowledgement

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