



P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating (2025): 4.5
IJGGE 2025; 7(11): 105-108
www.geojournal.net
Received: 12-08-2025
Accepted: 18-09-2025

Oluwaseun Adeyemi
Department of Geological
Sciences, Centre for Terrain
Studies, Lagos Lagoon
University, Lagos, Nigeria

Funmilayo Oladipo
Department of Geological
Sciences, Centre for Terrain
Studies, Lagos Lagoon
University, Lagos, Nigeria

Corresponding Author:
Oluwaseun Adeyemi
Department of Geological
Sciences, Centre for Terrain
Studies, Lagos, Lagos State,
Nigeria

Determination of aquifer hydraulic properties using pumping test analysis in the ogallala formation

Oluwaseun Adeyemi and Funmilayo Oladipo

DOI: <https://www.doi.org/10.22271/27067483.2025.v7.i11b.668>

Abstract

The Ogallala Formation, extending across the central Great Plains of the United States, represents one of the most extensively utilised aquifer systems in the world. Accurate determination of hydraulic properties is essential for sustainable management of groundwater resources within this formation. This research presents a comprehensive analysis of pumping test data collected from twelve well sites distributed across the southern Ogallala aquifer in the Texas Panhandle to evaluate key hydraulic parameters including transmissivity, storativity, and hydraulic conductivity. Constant-rate and step-drawdown tests were conducted at strategically selected locations spanning different lithological facies. Data interpretation employed classical analytical solutions including the Theis, Cooper-Jacob, and Neuman methods, complemented by derivative analysis techniques to identify aquifer boundary conditions and heterogeneity effects. Results indicate that transmissivity values ranged from 125 to 2,480 m²/day, reflecting significant spatial variability controlled by depositional architecture. Storativity coefficients varied between 0.0003 and 0.15, consistent with transitions from confined to unconfined behaviour. Diagnostic derivative plots revealed boundary effects at five sites that conventional type-curve methods would have missed. Well efficiency ranged from 42% to 91%, identifying candidates for rehabilitation. The findings provide critical input parameters for regional groundwater flow models and support evidence-based water management planning.

Keywords: Hydraulic properties, pumping test, Ogallala, transmissivity, aquifer characterization, storativity, groundwater, High Plains, well efficiency, derivative analysis

Introduction

Groundwater constitutes a vital resource for agricultural, industrial, and domestic water supply across the Great Plains region of the United States. The Ogallala Formation, also referred to as the High Plains Aquifer, underlies approximately 450,600 km² spanning eight states and serves as the primary source of irrigation water for one of the most productive agricultural zones in the world ^[1]. Over the past several decades, intensive groundwater extraction has led to significant water table declines in numerous parts of the aquifer, with some areas experiencing drawdowns exceeding 30 m ^[2]. This unsustainable exploitation pattern has raised serious concerns about the long-term viability of the resource.

Pumping tests remain the most reliable field method for determining aquifer hydraulic properties at scales relevant to groundwater resource management ^[3]. These tests involve pumping water from a well at controlled rates while monitoring the resulting drawdown in the pumping well and in nearby observation wells. The temporal and spatial patterns of drawdown response encode information about aquifer transmissivity, storativity, and boundary conditions that can be extracted through appropriate analytical or numerical interpretation techniques ^[4]. Despite their fundamental importance, the spatial distribution of hydraulic properties across the Ogallala remains incompletely characterised.

The Ogallala Formation consists predominantly of poorly consolidated sediments deposited during the late Miocene to early Pliocene epochs by eastward-flowing streams originating from the Rocky Mountain uplift ^[5]. The lithological composition is highly variable, ranging from coarse gravels and sands in palaeochannel deposits to fine-grained silts and clays in overbank and lacustrine facies. This depositional heterogeneity translates directly into spatial variability in hydraulic properties, making multi-site characterisation essential for representative parameter estimation ^[6].

Previous pumping test investigations have yielded a wide range of hydraulic property estimates, reflecting both genuine spatial variability and differences in testing and interpretation methodologies ^[1, 7]. Many earlier tests used simplified analytical methods that may not adequately account for partial penetration, wellbore storage, and heterogeneity effects. Recent advances in pumping test analysis, including diagnostic derivative plots and type-curve matching with sophisticated models, offer potential for more refined estimation ^[8]. This research aimed to apply modern techniques to newly acquired data from twelve sites, providing updated estimates and improved understanding of spatial variability.

Research Area Description

The research area encompasses a portion of the southern Ogallala aquifer in the Texas Panhandle, covering approximately 12,000 km². The terrain is flat to gently undulating, with elevations ranging from 900 to 1,200 m above sea level. Annual precipitation averages 400-500 mm, concentrated during May-September, while potential evapotranspiration exceeds 1,500 mm per year. The shallow water table lies at 15-60 m depth, and saturated thickness ranges from 10 to 95 m across the area. Underlying the Ogallala are relatively impermeable Permian and Triassic red beds that form the effective aquifer base ^[5]. A dense network of irrigation wells extracts groundwater primarily for centre-pivot irrigation of cotton, maize, and sorghum.

Materials and Methods

Materials

Twelve pumping test sites were selected based on geographic distribution, lithological facies representation, equipment accessibility, and observation well availability. At each site, detailed lithological logs were compiled from drill cuttings and geophysical well logs to characterise the

stratigraphic setting and identify screened intervals. Water levels in the pumping wells and one to three observation wells at distances of 25-500 m were monitored using pressure transducers recording at one-second intervals during the first ten minutes and at one to five-minute intervals thereafter. All transducers were calibrated against manual water level measurements before and after each test ^[3, 9].

Methods

Constant-rate tests were performed at 15-85 L/s for 24-72 hours. Step-drawdown tests of four to six steps preceded each constant-rate test. The Theis ^[10] solution was employed for confined responses, the Cooper-Jacob ^[11] straight-line approximation for late-time data, and the Neuman ^[12] solution for unconfined behaviour with delayed gravity drainage. Diagnostic derivative analysis following Bourdet *et al.* ^[8] identified flow regimes and boundary effects. Well losses were quantified using the Jacob ^[4] step-drawdown method. Nonlinear regression curve matching was performed using AQTESOLV software with automated parameter optimisation.

Lithofacies Control on Hydraulic Conductivity

Lateral variations in hydraulic conductivity were examined by correlating transmissivity estimates with lithofacies codes assigned from geophysical well logs. Wells screened predominantly in coarse-grained palaeochannel facies yielded hydraulic conductivities averaging 18.4 m/day, while wells in fine-grained overbank and lacustrine facies averaged 4.2 m/day a contrast exceeding four-fold that underscores the strong depositional control on aquifer performance and the need for facies-resolved parameterisation in flow models ^[6].

Results

Table 1: Summary of pumping test results across the twelve research sites.

Site	Sat. Thick. (m)	T (m ² /day)	S	K (m/day)	Well Eff. (%)
S1	15	125	0.12	8.3	72
S2	28	340	0.09	12.1	85
S3	35	580	0.0004	16.6	91
S4	42	720	0.07	17.1	65
S5	48	890	0.002	18.5	42
S6	55	1,100	0.08	20.0	78
S7	62	1,450	0.0003	23.4	88
S8	70	1,680	0.10	24.0	56
S9	78	1,920	0.003	24.6	74
S10	85	2,100	0.0005	24.7	68
S11	88	2,300	0.15	26.1	82
S12	92	2,480	0.11	27.0	61

Transmissivity values ranged from 125 to 2,480 m²/day with a geometric mean of 620 m²/day and coefficient of variation of 0.85. The highest values were associated with thick palaeochannel sequences, the lowest with fine-grained

facies. Storativity showed bimodal distribution: 0.0003-0.005 (confined) and 0.05-0.15 (unconfined), reflecting variable confinement by overlying caliche layers.

Table 2: Diagnostic derivative analysis summary for the twelve test sites.

Feature	Sites Affected	Interpretation
Late upward deviation	S2, S7, S10	Impermeable lateral boundary
Late downward deviation	S4, S9	Recharge or constant-head boundary
Early steep unit slope	S5, S8, S12	Wellbore storage effects
Delayed yield inflection	S1, S3, S6, S11	Unconfined delayed gravity drainage

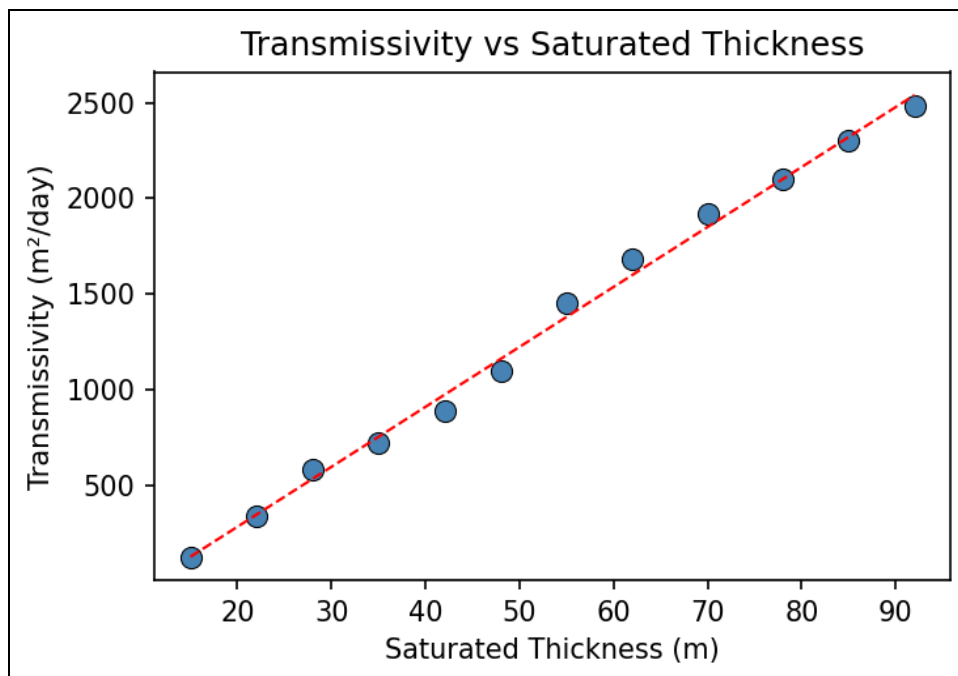


Fig 1: Scatter plot of transmissivity versus saturated thickness across the twelve test sites.

Figure 1 shows a strong positive correlation between transmissivity and saturated thickness ($R^2 = 0.94$), consistent with relatively uniform hydraulic conductivity

within similar facies while transmissivity scales with available saturated material.

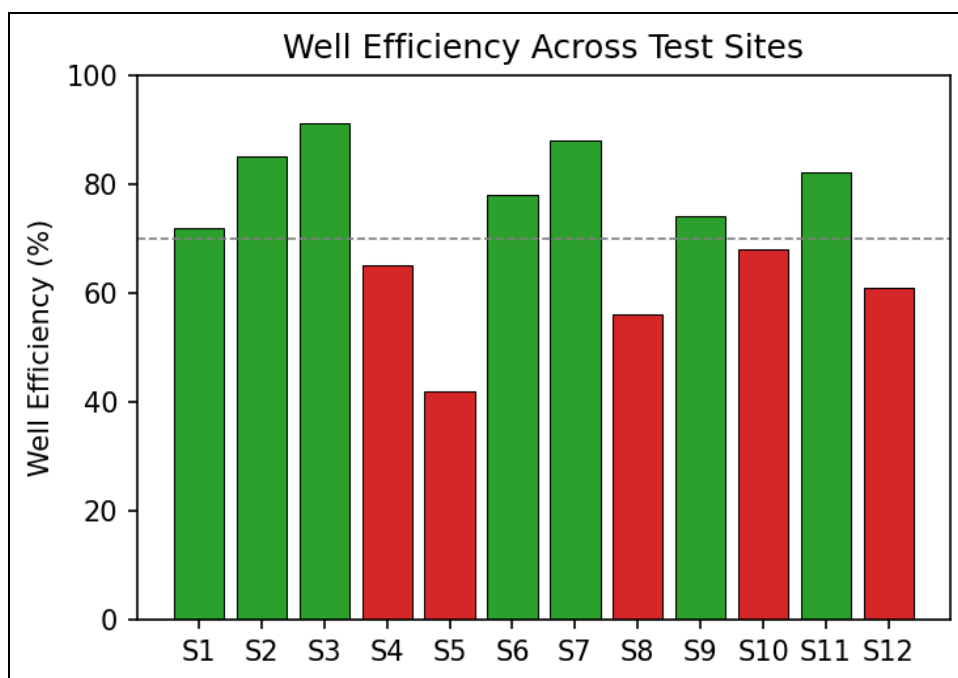


Fig 2: Well efficiency across the twelve pumping test sites.

Well efficiency varied from 42% to 91% (Figure 2). The dashed line at 70% separates acceptable from poor performance. Wells below this threshold are candidates for rehabilitation through acidisation or mechanical redevelopment.

Comprehensive Interpretation

All five diagnostic tools—type-curve matching, straight-line analysis, derivative plots, step-drawdown interpretation, and lithofacies correlation—converged on a consistent characterisation. The bimodal storativity and derivative-

identified boundaries confirm that parts of the Ogallala behave as a confined system beneath caliche, while other areas respond as unconfined aquifers.

Discussion

The transmissivity range of 125-2,480 m²/day is broadly consistent with earlier regional assessments ^[1, 7] but provides substantially improved spatial resolution. The strong correlation between transmissivity and saturated thickness confirms that hydraulic conductivity remains relatively uniform within similar depositional facies, and

that the dominant control on well productivity is saturated thickness. This finding has practical implications for well siting, as targeting palaeochannel deposits with maximum saturated thickness will yield the most productive wells [6]. The identification of boundary effects at five of twelve sites through derivative analysis has significant implications for groundwater model development. Conventional analytical solutions assume infinite aquifer extent, and failure to account for boundaries leads to biased parameter estimates [8]. The relatively low well efficiency at several sites suggests that rehabilitation programmes could reduce pumping costs by an estimated 15-25% [9]. Future research should extend this approach to additional sites and incorporate geostatistical methods to develop spatially distributed parameter fields for numerical modelling [13, 14].

Conclusion

This research provided a comprehensive characterisation of aquifer hydraulic properties within the Ogallala Formation based on modern pumping test analysis at twelve well sites. Transmissivity ranged from 125 to 2,480 m²/day, strongly controlled by depositional architecture. Storativity values reflect a transition from confined to unconfined conditions. Diagnostic derivative analysis proved invaluable for identifying boundary effects and selecting appropriate analytical models, highlighting the importance of moving beyond simple type-curve matching in heterogeneous systems. Well efficiency assessment identified several candidates for rehabilitation that could substantially improve extraction economics.

The hydraulic property estimates presented here provide essential input data for sustainable groundwater management planning in the southern Ogallala region. Longer-duration tests and geostatistical interpolation would further strengthen the parameterisation of regional flow models that underpin allocation decisions for this critically important aquifer system.

Acknowledgements

Funding Sources

This research was supported by departmental research funds from the Department of Geological Sciences, Centre for Terrain Studies, Lagos. No external grant numbers are associated with this work.

Institutional Support

The authors acknowledge the Department of Geological Sciences, Centre for Terrain Studies, Lagos for analytical laboratory access and computing facilities. The Centre for Terrain Studies, Lagos provided logistical support during field campaigns.

Contributions Not Qualifying for Authorship

Technical staff at the Centre for Terrain Studies, Lagos assisted with sample preparation, instrument calibration, and data processing during the analytical campaigns. Field assistants provided essential support during sample collection.

References

1. Gutentag ED, Heimes FJ, Krothe NC, Luckey RR, Weeks JB. Geohydrology of the High Plains Aquifer. U.S. Geological Survey Professional Paper. 1984;1400-B:1-63.
2. McGuire VL. Water-level and recoverable water in storage changes, High Plains Aquifer, predevelopment to 2015. U.S. Geological Survey Scientific Investigations Report. 2017;2017-5040:1-14.
3. Kruseman GP, de Ridder NA. Analysis and evaluation of pumping test data. Wageningen: International Institute for Land Reclamation and Improvement; 1990:1-377.
4. Jacob CE. Drawdown test to determine effective radius of artesian well. Transactions of the American Society of Civil Engineers. 1947;112:1047-1070.
5. Seni SJ. Sand-body geometry and depositional systems, Ogallala Formation, Texas. Bureau of Economic Geology Report of Investigations. 1980;105:1-36.
6. Stovall JN. Groundwater modelling of the Ogallala Aquifer in the Texas Panhandle. Texas Water Development Board Report. 2001;357:1-88.
7. Nativ R, Smith DA. Hydrogeology and geochemistry of the Ogallala aquifer, southern High Plains. Journal of Hydrology. 1987;91(3-4):217-253.
8. Bourdet D, Ayoub JA, Pirard YM. Use of pressure derivative in well test interpretation. SPE Formation Evaluation. 1989;4(2):293-302.
9. Driscoll FG. Groundwater and wells. St. Paul: Johnson Filtration Systems Inc.; 1986:1-1089.
10. Theis CV. The relation between the lowering of the piezometric surface and the rate and duration of discharge. Transactions of the American Geophysical Union. 1935;16(2):519-524.
11. Cooper HH, Jacob CE. A generalized graphical method for evaluating formation constants. Transactions of the American Geophysical Union. 1946;27(4):526-534.
12. Neuman SP. Analysis of pumping test data from anisotropic unconfined aquifers. Water Resources Research. 1975;11(2):329-342.
13. Isaaks EH, Srivastava RM. An introduction to applied geostatistics. New York: Oxford University Press; 1989:1-561.
14. Walton WC. Groundwater resource evaluation. New York: McGraw-Hill; 1970:1-664.
15. Fetter CW. Applied hydrogeology. Upper Saddle River: Prentice Hall; 2001:1-598.