International Journal of Coal, Geology and Mining Research
Vol.7, No.1, pp.21-26, 2025
Website: https://www.eajournals.org/
Published by European Centre for Research Training and Development UK

Quantification of Uncertain Parameters of Water Influx in a Reservoir under Artesian Water Drive

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Citation: Ndem D.O. (2025) Quantification of Uncertain Parameters of Water Influx in a Reservoir under Artesian Water Drive, *International Journal of Coal, Geology and Mining Research*, 7(1), 21-26

Abstract: *This study quantifies the uncertain parameters of water influx in a reservoir under an artesian water drive using a combination of analytical and numerical methods. A numerical model was developed using Schlumberger Eclipse reservoir simulation software, and a Monte Carlo simulation was performed with 1000 runs to propagate uncertainty in parameters. The results indicate a significant uncertainty in water influx rates, with a mean value of 520 m³/day and a standard deviation of 160 m³/day. Sensitivity analysis revealed that permeability and aquifer size are the most influential parameters affecting water influx, with sensitivity coefficients of 0.45 and 0.35, respectively. The 10th and 90th percentiles of the water influx rate were 340 m³/day and 710 m³/day, respectively. The study highlights the need for a probabilistic approach to account for uncertainty in reservoir simulation models and demonstrates the importance of quantifying uncertain parameters in predicting water influx rates. The results can be used to inform decision-making and optimize reservoir management strategies*.
Keywords: water influx, uncertain parameters, artesian water drive, permeability, aquifer size, quantification

INTRODUCTION

Petroleum reservoirs are frequently encompassed by water aquifers that back up the reservoir pressure through water inflow. When the pressure declines in a petroleum reservoir, the water aquifer responds by providing an influx of water. Gradually, the damage is reduced and then eliminated, and more oil is produced from the reservoir. Mehaysen et al. (2023). Water influx in a reservoir under artesian water drive is a complex phenomenon that involves the interaction of multiple reservoir and aquifer properties. Accurate prediction of water influx is crucial for effective reservoir management, as it can significantly impact the reservoir's production performance and ultimate recovery. However, uncertainty in reservoir and aquifer properties can significantly impact the accuracy of these predictions. Various procedures such as Bayesian statistical inference techniques and statistical assessment process have been used to understand the uncertainty in predicting water influx, Bayesian procedures enable the combination of pre-existing understanding of model parameters and observed information with the output of the model. This leads to a likelihood distribution in the parameter space that sums up uncertainty concerning the parameters; this is regarded as the reverse distribution. The possibility to utilize a precise prior should be based on existing parameter knowledge (Tsamba et al. 2019).

He et al. (2018) integrated non-probability set theory and interval uncertainty analysis to develop predictive formulas for water influx under two conditions. The first formula was derived from the initial deterministic simple large-well method, while the second formula considered parameter variation uncertainty. Using mining data, the authors compared the calculated bounds obtained by the Monte

Carlo method with those derived from the formulas. The results showed that the relative errors of the confined water inflow expressions were within 5% and 10% for both formulas. The study found that for the first formula, the relative errors of 5% and 10% corresponded to parameter variable change rates of 0.109 and 0.14, respectively. For the second formula, the relative errors of 5% and 10% corresponded to parameter variable change rates of 0.274 and 0.131, respectively. The results indicate that, under identical error conditions, the maximum parameter change rates are greater than the minimum parameter change rates, which is beneficial for calculating the upper limit of mine water inflow.

Mehaysen, et al. (2023) conducted a comprehensive study to quantify water influx in the Hamzeh oil reservoir, situated in northeastern Jordan, approximately 150 km east of Amman. The material balance equation (MBE) was employed as the primary method to predict reservoir performance over an 11-year period. The study's results indicate that the reservoir is characterized by a water drive technique, with an estimated original oil in place (OOIP) of 24,958,290 m^3. Predicted oil recovery factors ranged from 10.9% to 25% for the Hummar and Shueib formations, respectively, contingent upon areal efficiency assumptions. Furthermore, water influx predictions for the 11-year period were generated using the MBE, an unsteady-state model, and performance reservoir analysis. The integrated approach provided a robust framework for quantifying water influx and informing reservoir management strategies.

Water influx from surrounding aquifers plays a crucial role in maintaining reservoir pressure in petroleum reservoirs. In response to pressure depletion, the aquifer reacts by providing a water influx or encroachment, thereby offsetting or retarding the pressure decline BinMerdhah et al., (2015). Understanding the relationships between reservoir pressure, hydrocarbon production, and reservoir fluid properties is essential for predicting reservoir performance. An equation that enables the calculation of oil content and quantitatively predicts the impact of gas-oil ratio on reservoir pressure decline was studied, the key parameters influencing water encroachment rates and totals include active oil and reservoir energy (Schilthuis, 1936; Hurst, 1943). An approach that offers a flexible and useful method for forecasting and evaluating the performance of water-drive reservoirs has been developed (Fetkovich, 1971). Analysis of skin factors reveals severe wellbore damage in the assessed oil wells, which were subsequently treated with matrix acidizing. The acid treatment, applied to the Hummar and Shueib formations, successfully enhanced well productivity (Al-Mehaysen et al., 2021).

Early water breakthrough in oil reservoirs can be attributed to various factors, including pressure depletion and strong water drive.

Aliu et al. (2024) investigated the role of aquifer support in the safsaf C reservoir by conducting a comprehensive analysis using material balance equations (MBEs) coupled with the pot aquifer water influx model. The study revealed that the reservoir experienced early water breakthrough merely 62 days after the commencement of oil production. To establish the presence and strength of the aquifer, the authors employed a Campbell plot, which indicated a weak aquifer. Further analysis using the Solution plot confirmed the presence of an aquifer. The pot aquifer plot yielded an estimate of the original aquifer in place, approximately 28.42 mmRB, which is roughly half the size of the estimated hydrocarbon pore volume (51.15 mmRB). Water influx plots generated improved estimates of Oil Initially In Place (OIIP), ranging from 11.50 to 12.20 mmSTB. The aquifer influx profiles showed that water encroaches into the reservoir at a rate of 742 rbl/d. This study demonstrates the applicability of material balance analysis in assessing aquifer support in reservoirs bounded by small aquifers, particularly when limited information is available. The approach provides reliable estimates of OIIP and the degree of aquifer support, enabling informed decision-making for reservoir management and development.

Nmegbu et al. (2021) conducted a comprehensive study to investigate the impact of aquifer geometry on oil recovery factors. The research focused on two primary aquifer configurations: bottom and edge water aquifers. The study's methodology involved: 1. Aquifer characterization using influx models to estimate key properties such as permeability and porosity. 2. Utilization of Material Balance Software (MBAL) to regress aquifer properties and history-match average reservoir pressure with computed pressure. 3. Sensitivity analysis on aquifer parameters using the Fetkovich model for bottom and edge water drive. The results showed that bottom water drive yielded a 0.40% increase in cumulative oil volume compared to edge water drive. Furthermore, sensitivity analysis revealed that reservoir size increases exponentially with aquifer volume in bottom water drive, whereas edge water drive exhibits a linear relationship. Aquifer volume and permeability demonstrate linear relationships with both bottom and edge water drive. The result highlighted the importance of accurate aquifer characterization and modelling for optimized reservoir management.

Bardy et al. (2019) addressed the challenge of predicting underground fluid flow in hydrocarbon reservoirs due to geological and petrophysical uncertainties. A novel workflow was proposed to assess dynamic reservoir behaviour uncertainties, estimate analytical production curves using proxy distances, compute accurate flow responses on a subset of ensemble models, and employ randomization to assess confidence intervals. The workflow accommodates static and dynamic proxies, enabling efficiency comparisons. A case study demonstrated the method's applicability, highlighting the value of simple proxies in increasing confidence about future reservoir production

METHODOLOGY

The quantification of uncertain parameters of water influx in a reservoir under artesian water drive was achieved through a combination of analytical and numerical methods. The following steps were taken:

Data Collection

Relevant data, including reservoir properties, water influx rates, and pressure data, were collected from existing literature and field reports.

Table 2.1a: Reservoir Properties

Permeability (mD)	Porosity (%)	Thickness (m)	Temp (°F)	Pressure (psi)
300	22	3500	80	2000

Table 2.1b: Aquifer Properties

Permeability (mD)	Porosity (%)	Thickness (m)	Water Influx Rate (m^3/day)	Temp (°F)	Pressure (psi)
120	15	108	1000	70	1500

Table 2.1c: Historical Production and Pressure Data

Date	Well Name	Oil Production Rate	Water Production Rate	Pressure (psi)	Pressure Change (dp/dt)	Water Influx Rate
2020-01-01	AD1	1000	100	2500	0.5	500
2020-02-01	AD2	800	120	2200	0.6	600
2020-03-01	AD3	600	150	2000	0.7	700
2020-04-01	AD4	400	180	1800	0.8	800
2020-05-01	AD5	200	200	1600	0.9	900

Model Development
The Eclipse simulation was performed using the Schlumberger Eclipse reservoir simulation software. The simulation model was built based on the reservoir properties, fluid properties, and rock properties. The simulation model consisted of a 3D grid representing the reservoir geometry. The grid was populated with properties such as permeability, porosity, and initial water saturation.

Sensitivity Analysis
A sensitivity analysis was conducted to identify the most influential parameters affecting water influx. The parameters considered included permeability, porosity, aquifer size, and reservoir pressure.

Uncertainty Quantification
The uncertain parameters were quantified using a probabilistic approach, where probability distribution functions (PDFs) were assigned to each parameter.

Table 2.4: Assigned PDFs for Uncertain Parameters

Parameter	PDF	Mean	Standard Deviation
Permeability (mD)	Normal	300	50
Porosity (fraction)	Normal	0.2	0.05
Aquifer Size (acres)	Uniform	2000	1000
Reservoir Pressure (psi)	Normal	2500	200

Monte Carlo Simulation
A Monte Carlo simulation was performed to propagate the uncertainty in the parameters through the numerical Eclipse model. The simulation consisted of 1000 runs, each with a different set of parameter values sampled from the assigned PDFs.

RESULTS

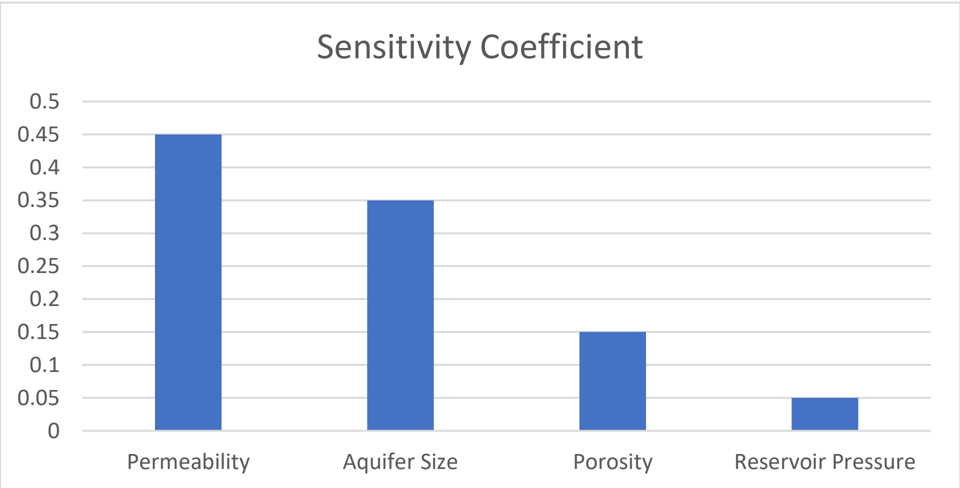

Fig 1. Sensitivity analysis of parameters affecting water influx

Table 3: Monte Carlo Simulation Results

Statistic	Water Influx Rate (m^3/day)
Mean	520
Standard Deviation	160
10th Percentile	340
90th Percentile	710

Table 4: Probability Distribution Function of Water Influx Rate Range

Water Influx Rate Range (m^3/day)	Probability
200-300	0.05
300-400	0.15
400-500	0.25
500-600	0.30 (peak at 520)
600-700	0.20
700-800	0.05

DISCUSSIONS

The results of the study indicate that the uncertain parameters have a significant impact on water influx rates. The sensitivity analysis revealed that permeability and aquifer size are the most influential parameters affecting water influx.

The uncertainty quantification and Monte Carlo simulation provided a range of possible water influx rates, highlighting the need for further data collection and model refinement to reduce uncertainty. The results of this study can be used to inform decision-making and optimize reservoir management strategies

CONCLUSIONS

The study demonstrates the importance of quantifying uncertain parameters in predicting water influx rates in reservoirs under an artesian water drive. The results highlight the need for a probabilistic approach to account for uncertainty in reservoir simulation models.

The following conclusions can be drawn from the study:

- The uncertain parameters have a significant impact on water influx rates.
- Permeability and aquifer size are the most influential parameters affecting water influx.
- Further data collection and model refinement are necessary to reduce uncertainty and improve the accuracy of water influx predictions.
- The results of this study can be used to inform decision-making and optimize reservoir management strategies.

REFERENCE

He, S., Yin, X., Yu, C., Xu, Z., & Yang, Z. (2018). Quantifying parameter uncertainty in reservoir operation associated with environmental flow management. Journal of Cleaner Production, 176, 1271-1282.

Al-Mahasneh, M., Al-Khasawneh, H. E., Al-Zboon, K., & Aljarrah, A. (2023). Water Influx Impact on Oil Production in Hamzeh Oil Reservoir in Northeastern Jordan: Case Study. *Energies*, *16*(5), 2126. https://doi.org/10.3390/en16052126

Tsamba, I.I., Lucas, L.H., and Skalle, P. (2019). A dry gas material balance with an infinite aquifer influence: A comparative study between the unsteady state model of van Edverdingen-Hurst and analytical model. Journal of Petroleum and Gas Engineering. Vol, 10(4), pp 56-64. Doi:10.5897/JPGE2019-0306

BinMerdhah, A.B.; Muherei, M.A.; Al-Khudafi, A.M.; Bamumen, S.S. Prediction of Water Influx Effect on Oil Production in Biyad Oil Reservoir. Hadhramaut Univ. *J. Nat. Appl. Sci.* **2015**, *12*, 9–21.

Schilthuis, R.J. Active Oil and Reservoir Energy. *Trans. AIME* **1936**, *118*, 33–52.

Hurst, W. Water Influx Into a Reservoir and Its Application to the Equation of Volumetric Balance. *Trans. AIME* **1943**, *151*, 57–72.

Fetkovich, M. A Simplified Approach to Water Influx Calculations-Finite Aquifer Systems. *J. Pet. Technol.* **1971**, *23*, 814–828.

Al-Mahasneh, M.; Al Rabadi, S.; Khaswaneh, H. (2021) Assessment of oil-producing wells by means of stimulation approach through matrix acidizing: A case study in the Azraq region. *J. Pet. Explor. Prod. Technol.* **2021**, *11*, 3479–3491.

Nmegbu, C.G.J., Ebube, O.F. and Edet, E.A. (2021). Comparative Study of Oil Recovery Factor Determination for Edge and Bottom Water Drive Mechanism Using Water Influx Models. *European Journal of Engineering and Technology Research*. 6, 5 (Jul. 2021), 1–9. DOI:https://doi.org/10.24018/ejeng.2021.6.5.2493.

Bardy, G., Biver, P., Caumon, G., and Renard, P. (2019). Oil production uncertainty assessment by predicting reservoir production curves and confidence intervals from arbitrary proxy responses. Journal of Petroleum Science and Engineering, 176, 116-125.

Aliu, H. O., Alawode, A. J., and Falade, A. A. (2024). Material balance analysis of water influx into an undersaturated oil reservoir using pot aquifer model: A case study. Geosystem Engineering, 28(1), 46–60. doi: 10.1080/12269328.2024.2417076