Pywaterflood: Well connectivity analysis through capacitance-resistance modeling

Frank Male [1]¶

1 Pennsylvania State University, University Park, PA, USA ¶ Corresponding author

Summary

Well connectivity analysis has many applications for subsurface energy, from waterfloods to CO_2 floods to geothermal. Capacitance Resistance Models are useful for performing well connectivity analysis with limited information about the geology of the reservoirs involved. They are so-called because the equations describing well influence mimic a network of capacitors and resistors.

Pywaterflood is a Python package that uses Capacitance Resistance Modeling to estimate well connectivity. The CRM submodule forms the bulk of this package. It can perform capacitance resistance modeling with differing levels of complexity, from assuming that producing and injecting wells share one universal time constant, to each producer has the same time constant with all injectors, to each producer-injector pair has an its own time constant. CRM was developed by Yousef et al. (2006). The MPI submodule uses a geometrical model of well influence (Valko et al., 2000), extended and applied to reservoirs with both injecting and producing wells (Kaviani & Valkó, 2010).

Statement of need

Interwell connectivity analysis is important for understanding the geology of subsurface systems. This can be used to improve oil recovery efficiency (Albertoni & Lake, 2003), better sequester CO_2 (Tao & Bryant, 2015), and optimize geothermal fields (Akin, 2014).

Pywaterflood uses a reduced-physics model to match connections between injecting and producing wells. As explained in Holanda et al. (2018), capacitance-resistance modeling provides a method for connectivity analysis more sophisticated than empirical decline analysis, but more approachable than full reservoir simulation.

There is another publicly available tool for capacitance resistance modeling reservoirs like pywaterflood (Sayarpour, 2008). However, that tool comes in the form of an Excel workbook and no associated license. This python package provides more extensibility and better performance than an Excel file. There are other programs for performing waterflood analysis with CRM in the industry, but they are not open sourced and available for researchers to use.

The pywaterflood library can perform the following tasks:

1. Estimate connectivity between wells in fluid or pressure communication
2. History-match and forecast the production of wells in waterfloods, CO_2 floods, or geothermal fields
3. Provide purely geometric estimates of well connectivity before production data is available

Acknowledgements

References

Akin, S. (2014). Optimization of reinjection allocation in geothermal fields using capacitance-resistance models. *Thirty-Ninth Workshop on Geothermal Reservoir Engineering. Stanford University*. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2014/Akin.pdf

Albertoni, A., & Lake, L. W. (2003). Inferring interwell connectivity only from well-rate fluctuations in waterfloods. *SPE Reservoir Evaluation & Engineering*, *6*(01), 6–16. https://doi.org/10.2118/83381-PA

Harris, C. R., Millman, K. J., Walt, S. J. van der, Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N. J., Kern, R., Picus, M., Hoyer, S., Kerkwijk, M. H. van, Brett, M., Haldane, A., Río, J. F. del, Wiebe, M., Peterson, P., … Oliphant, T. E. (2020). Array programming with NumPy. *Nature*, *585*(7825), 357–362. https://doi.org/10.1038/s41586-020-2649-2

Holanda, R. W. de, Gildin, E., Jensen, J. L., Lake, L. W., & Kabir, C. S. (2018). A state-of-the-art literature review on capacitance resistance models for reservoir characterization and performance forecasting. *Energies*, *11*(12). https://doi.org/10.3390/en11123368

Kaviani, D., & Valkó, P. P. (2010). Inferring interwell connectivity using multiwell productivity index (MPI). *Journal of Petroleum Science and Engineering*, *73*(1-2), 48–58. https://doi.org/10.1016/j.petrol.2010.05.006

McKinney, Wes. (2010). Data Structures for Statistical Computing in Python. In Stéfan van der Walt & Jarrod Millman (Eds.), *Proceedings of the 9th Python in Science Conference* (pp. 56–61). https://doi.org/10.25080/Majora-92bf1922-00a

Sayarpour, M. (2008). *Development and application of capacitance-resistive models to water/carbon dioxide floods*. The University of Texas at Austin. https://repositories.lib.utexas.edu/handle/2152/15357

Tao, Q., & Bryant, S. L. (2015). Optimizing carbon sequestration with the capacitance/resistance model. *SPE Journal*, *20*(05), 1094–1102. https://doi.org/10.1016/j.egypro.2013.06.290

Valko, P. P., Doublet, L., & Blasingame, T. (2000). Development and application of the multiwell productivity index (MPI). *SPE Journal*, *5*(01), 21–31. https://doi.org/10.2118/51793-PA

Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., van der Walt, S. J., Brett, M., Wilson, J., Millman, K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R., Larson, E., … SciPy

1.0 Contributors. (2020). SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python. *Nature Methods*, *17*, 261–272. https://doi.org/10.1038/s41592-019-0686-2

Walt, S. van der, Colbert, S. C., & Varoquaux, G. (2011). The NumPy array: A structure for efficient numerical computation. *Computing in Science & Engineering*, *13*(2), 22–30. https://doi.org/10.1109/MCSE.2011.37

Yousef, A. A., Gentil, P., Jensen, J. L., & Lake, L. W. (2006). A capacitance model to infer interwell connectivity from production-and injection-rate fluctuations. *SPE Reservoir Evaluation & Engineering*, *9*(06), 630–646. https://doi.org/10.2118/95322-PA