**Reservoir Productivity Uncertainty Analysis for the Tuscarora Sandstone, Morgantown, WV
DE-EE0008105: Feasibility of Deep Direct-Use Geothermal on the West Virginia University Campus-Morgantown, WV**

The purpose of this document is to describe the contents of information contained within a submission to the Geothermal Data Repository (GDR) node of the National Geothermal Data System (NGDS) in support of Feasibility of Deep Direct-Use Geothermal on the West Virginia University Campus-Morgantown, WV.

**Abstract**: This dataset contains figures that summarize the Tuscarora Sandstone core permeability data collected from the Preston 119 well in Preston County, WV, and summary results of a stochastic analysis that was used to estimate reservoir productivity for the currently unexplored Tuscarora Sandstone below Morgantown, West Virginia. Uncertainties in reservoir productivity considered the thickness of the reservoir, rock permeability, and fluid viscosity. A Monte Carlo analysis of these uncertain properties was used to predict reservoir flow productivity for the case of a matrix-dominated reservoir, and a fracture-dominated reservoir. These results are summarized in figures, spreadsheets, and maps. Detailed descriptions of the contents of this repository are provided below.

Supporting data for this analysis was provided by the West Virginia Geologic and Economic Survey (McDowell et al., 2018). The methods used for analysis and a detailed discussion of the results are presented in a paper by Smith (2019). Some of the information used for this uncertainty analysis are provided in other data and code repositories that describe: methods for Monte Carlo uncertainty analysis of natural reservoir productivity in the Appalachian Basin (Camp et al., 2018), natural reservoir productivity analysis results for the Appalachian Basin (GDR submission #881; Cornell University, 2016), and the original code used for that analysis (Whealton and Smith, 2015). The code was updated for use in this analysis, and the updated code is provided in this repository.

The Appalachian Basin reservoir productivity maps provided in Cornell University (2016) are updated in this repository by adding the Morgantown Tuscarora to the maps. In contrast to all other reservoirs, the Morgantown Tuscarora is not yet known to exist with the properties assumed in this study because no well has been drilled to the Tuscarora depth below Morgantown.

**Key Words**: Appalachian Basin, West Virginia University, Tuscarora Sandstone, sedimentary reservoir, reservoir flow geometry, reservoir productivity assessment, permeability, matrix, fracture, uncertainty analysis.

**Citation**: When referencing this data, please use the following citation information:

**Title**: WVU DDU: Tuscarora Sandstone Flow Productivity Uncertainty Analysis Results for Morgantown, WV

 **Author(s)**: West Virginia University, Cornell University

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**Dependencies:**

The MATLAB code depends on the function “csvwrite\_with\_headers.m” by Keith Brady (n.d.).

**Contents of Submission**:

**Folder: AppalachianBasinReservoirShapefiles**

Contains a shapefile of the Appalachian Basin reservoirs that were evaluated as potential geothermal reservoirs in the Geothermal Play Fairway Analysis of the Appalachian Basin (Camp et al., 2018; original shapefile from Cornell University, 2016). To this shapefile, a polygon for the Morgantown Tuscarora Sandstone was added. A figure of that polygon is provided. The attribute table for the shapefile is described in the Cornell University (2016) GDR submission and associated content links.

 **Contents**

1. **Shapefile: GPFAReservoirs2018.dbf, GPFAReservoirs2018.prj, GPFAReservoirs2018.qpj, GPFAReservoirs2018.shp, and GPFAReservoirs2018.shx**

The Appalachian Basin reservoir dataset updated with information for Morgantown Tuscarora.

1. **File: Figure1\_Map\_MorgantownTuscaroraEstimatedSpatialExtent.png**

Map of the estimated spatial extent of the Tuscarora reservoir for Morgantown. A description of the assumptions made to determine the spatial extent is provided in Smith (2019).

**Folder: Preston119\_PermeabilityDataAnalysis**

Contains figures illustrating the permeability data collected from core measurements sampled from the Preston 119 well in Preston County, WV. Raw air permeability-depth data were provided by the West Virginia Geologic and Economic Survey (WVGES) (McDowell et al., 2018).

 **Contents:**

1. **File: WaterPermeabilityDepthPreston119\_NoClosedFracs\_Avg\_log.png**

Figure of the Klinkenberg-estimated water permeability for the Preston 119 well’s Tuscarora core permeability measurements. This plot provides only those measurements that were sampled on fractures that would likely be open at depth, corresponding to dips greater than 20° (colored points) and other features, like matrix rock (black points). The plotted points correspond to the average of the 3 measurements that were taken in each location. It is plotted in log-space on the x-axis.

1. **Files: WaterAvgPermBreakdown\_NoClosedFracs\_NewLegend.png, and WaterAvgPermBreakdown\_NoClosedFracs.png**

Histograms of the Preston 119 permeability data colored by the type of feature. The plot with “NewLegend” in the title appears in Smith (2019).

1. **File: LNfitAvgWaterPerm\_Mat.png**

Lognormal distribution fits to the observed matrix rock permeability in the Preston 119 Tuscarora core.

1. **Files: LNfitAvgWaterPerm\_All\_OpenFracs.png, and LNfitGeomWaterPerm\_All\_OpenFracs.png**

Lognormal distributions fit to the average (LNfitAvg) or geometric mean (LNfitGeom) of bootstrapped random samples of the Preston 119 permeability data. All features were considered, and only likely open fractures at depth were considered.

1. **File: PermVario\_OpenFracs\_log.png**

Variogram cloud and mean estimates of log(water permeability) along the core of the Preston 119 Tuscarora. Only likely open fractures at depth were considered.

**Folder: TuscaroraReservoirProductivityAnalysis**

Contains the code used for analysis (modified from Whealton and Smith, 2015), input data, and output results for the reservoir productivity uncertainty analysis.

**Contents**

1. **Folder: Code**
	1. **File: GenRandNums.m**

Random number generation file modified from Whealton and Smith (2015) to meet the requirements of the Morgantown Tuscarora analysis.

* 1. **File: Main\_Productivity.m**

Main script used to run the uncertainty analysis, modified from Whealton and Smith (2015) to meet the requirements of the Morgantown Tuscarora analysis.

* 1. **File: MonteCarloApprox.m**

Monte Carlo script, modified from Whealton and Smith (2015) to meet the requirements of the Morgantown Tuscarora analysis.

1. **Folder: InputDatasets**
	1. **File: UncertaintyLevels09-09-16.csv**

File describing the uncertainty levels, as described in Camp et al. (2018).

* 1. **File: RPIw\_MorgantownTuscarora\_Mat.csv**

File describing the distributions and parameters for the uncertainty analysis of the RPIw flow productivity metric for matrix rock.

* 1. **File: RFC\_MorgantownTuscarora\_Mat.csv**

File describing the distributions and parameters for the uncertainty analysis of the RFC flow productivity metric for matrix rock.

* 1. **File: RFC\_MorgantownTuscarora\_All.csv**

File describing the distributions and parameters for the uncertainty analysis of the RFC flow productivity metric for all features observed in the Preston 119 core permeability dataset. Only likely open fractures were considered in this analysis.

1. **Folder: Results**
	1. **Folder: RFC\_MatOpenFracs**

RFC for “all” permeability data, which considers the permeability distribution for matrix rock and fractures likely to be open at depth (Smith, 2019)

* + 1. **File: RFC\_MorgantownTuscarora\_Results\_All.csv**

contains summary information, including the mean, standard deviation, coefficient of variation, and percentiles of the Monte Carlo distributions for the RFC for all permeability data with likely open fractures for each RsvNum (scenario).

* + 1. **File: RFC\_MorgantownTuscarora\_ResultsAll\_All.csv**

contains all Monte Carlo replicates for each RsvNum (scenario). The summary data were computed from this spreadsheet.

* + 1. **Files: MorgantownTuscaroraAllRFCs.png, and MorgantownTuscaroraAllRFCs\_GeomMean.png**

Histogram of the RFC Monte Carlo replicates from the RFC\_MorgantownTuscarora\_ResultsAll\_All.csv results corresponding to the geometric mean (GeomMean file) and the average fracture-dominated permeability.

* + 1. **Files: EcdfPlot\_RFCAll\_ArithGeoMean.png**

Empirical cumulative distribution plots for the RFC replicates corresponding to arithmetic mean and geometric mean fracture-dominated permeability. Results are plotted for different probability distribution assumptions, and different average reservoir thicknesses.

* + 1. **Files: RiskMap\_RFC\_AllOpenFracs.png, and RiskMap\_RFC\_All\_CV.png**

Maps of the Appalachian Basin reservoir mean and coefficient of variation (CV) for the RFC. For Morgantown, these maps display the arithmetic mean fracture-dominated permeability results.

* + 1. **Files: RiskMap\_RFC\_AllOpenFracs\_GeoMean.png, and RiskMap\_RFC\_All\_CV\_GeoMean.png**

Maps of the Appalachian Basin reservoir mean and coefficient of variation (CV) for the RFC. For Morgantown, these maps display the geometric mean fracture-dominated permeability results.

* 1. **Folder: RFC\_Matrix**

RFC for matrix permeability data only.

* + 1. **File: RFC\_MorgantownTuscarora\_Results\_Mat.csv**

contains summary information, including the mean, standard deviation, coefficient of variation, and percentiles of the Monte Carlo distributions for the RFC for matrix rock for each RsvNum (scenario).

* + 1. **File: RFC\_MorgantownTuscarora\_ResultsAll\_Mat.csv**

contains all Monte Carlo replicates for each RsvNum (scenario). The summary data were computed from this spreadsheet.

* + 1. **File: MorgantownTuscaroraMatrixRFCs.png**

Histogram of the RFC Monte Carlo replicates from RFC\_MorgantownTuscarora\_ResultsAll\_Mat.csv.

* 1. **Folder: RPIw\_Matrix**

RPIw for matrix permeability data only.

* + 1. **File: RPIw\_MorgantownTuscarora\_Results\_Mat.csv**

contains summary information, including the mean, standard deviation, coefficient of variation, and percentiles of the Monte Carlo distributions for the RPI for matrix rock for each RsvNum (scenario).

* + 1. **File: RPIw\_MorgantownTuscarora\_ResultsAll\_Mat.csv**

contains all Monte Carlo replicates for each RsvNum (scenario). The summary data were computed from this spreadsheet.

* + 1. **Files: EcdfPlot\_RPIwMat.png, and EcdfPlot\_RPIwMat\_newCols.png**

Empirical cumulative distribution plot for the RPIw replicates. Results are plotted for different well separations and different probability distribution assumptions. The color scheme is different between these two files.

* + 1. **File: MorgantownTuscaroraMatrixRPIw.png**

Histogram of the RPIw Monte Carlo replicates from RPIw\_MorgantownTuscarora\_ResultsAll\_Mat.csv.

* + 1. **Files: RiskMap\_RPIw\_Mat.png, and RiskMap\_RPIw\_Mat\_CV.png**

Maps of the Appalachian Basin reservoir mean and coefficient of variation (CV) for the RPIw. For Morgantown, these maps display the matrix-dominated RPIw results.

* 1. **Files: RPIResults\_Morgantown\_2018.csv, and RPIResults\_Morgantown\_2018\_Geom.csv**

Results of the reservoir productivity index (RPI) and reservoir flow capacity (RFC) for Appalachian Basin reservoirs, including one row for the Morgantown Tuscarora (number 1964). For the Morgantown Tuscarora, both spreadsheets have the RPI for matrix rock. For the Morgantown Tuscarora, the RFC for the geometric mean fracture-dominated permeability is reported in the \_Geom file, and the RFC for average fracture-dominated permeability is provided in the other file. Other reservoirs have the productivity as reported in Camp et al. (2018) (from Cornell University, 2016).

**References**

Brady, K. (n.d.). csvwrite\_with\_headers.m [code]. Retrieved on Nov. 17, 2019 from https://www.mathworks.com/matlabcentral/fileexchange/29933-csv-with-column-headers?focused=5176300&tab=function

Camp, E., T.E. Jordan, M.J. Hornbach, and C.A. Whealton. (2018). A probabilistic application of oil and gas data for exploration stage geothermal reservoir assessment in the Appalachian Basin. Geothermics, 71. Pp. 187 – 199.

Cornell University. (2019). Appalachian Basin Temperature-Depth Maps and Structured Data in support of Feasibility Study of Direct District Heating for the Cornell Campus Utilizing Deep Geothermal Energy [data set]. Retrieved from http://gdr.openei.org/submissions/1182.

Cornell University. (2016). Natural Sedimentary Reservoirs Data Geothermal Play Fairway Analysis 2016 Revision [data set]. Retrieved from http://gdr.openei.org/submissions/881.

McDowell, R., J. Lewis, and G. Daft, compilers. (2018). Permeability data acquired by direct air injection from the Silurian Tuscarora Sandstone interval – Preston 119 drill core [dataset]. West Virginia Geological and Economic Survey.

Smith, J.D.. (2019). A stochastic evaluation of geothermal reservoir potential for the Tuscarora Sandstone in Morgantown, West Virginia, USA. 43rd GRC Annual Meeting & Expo, Palm Springs, CA. Sept. 16.

Whealton, C.A., and J.D. Smith. (2015). geothermal\_pfa/reservoir\_ideality [code]. GitHub repository commit from Apr 7, 2015 with label cfea0214311535f9c16272ce825f3550fdfc5ec1 retrieved from https://github.com/calvinwhealton/geothermal\_pfa/tree/master/reservoir\_ideality