# Appendix 6

# Permeability Distribution Maps & Workflow

Geostock Sandia

**PERMEABILITY WORKFLOW**

Twenty-seven total wells had existing core data within 5 miles of the defined model boundary, which could be used to build a relationship between porosity and permeability for the Static Earth Model (SEM) (**Figure 1**). Of these wells twenty-four came from the Shreveport Petroleum Data Association (SPDA), two are from an offset Class I injection project in El Dorado County, and one is from the Texas Bureau of Economic Geology (BEG). There are 21 wells which have data in the Hosston, and nine which have data in the Cotton Valley (**Table 1**). The core data described above was used to develop porosity to permeability mathematical transforms as mentioned in *Module B: Section 3.3 Table 10*. The method used to develop k-phi mathematical functions for the SEM was based upon the Swansons mean methodology (Delfiner, 2007), which in summary uses an analysis based upon quartiles of permeability representing the tenth, fiftieth, and ninetieth quantiles of the permeability data across bins of porosity ranges. In the petroleum industry the Swansons mean analysis has been demonstrated to yield permeability ranges significantly closer to actual permeability in reservoirs as opposed to using a simple mean. The equation for Swansons mean is shown below.

$$\text{K-phi} = 0.3*(K_{10}) + 0.4*(K_{50}) + 0.3*(K_{90})$$

Where:

$K_{10}$= permeability of the 10$^{th}$ quantile of data within a representative porosity bin.

$K_{50}$= permeability of the 50$^{th}$ quantile of data within a representative porosity bin.

$K_{90}$= permeability of the 90$^{th}$ quantile of data within a representative porosity bin.

The Swansons mean analysis is done through a series of steps and then a QA/QC versus the original porosity and permeability data. **Figure 2** demonstrates the data and steps used to build the Swansons permeability transform for the lower Hosston formation in the Project Blue CCS site. The steps to the analysis are as follows:

- Define the minimum and maximum values of the porosity data.
- Based upon the range of the porosity chose a bin spacing of porosity units to analyze the data.
    - For the Project Blue CCS porosity bins of 2 porosity units were utilized
- Calculate the average porosity value in each of the porosity unit bins.
- Calculate the permeability values that represent the 10$^{th}$, 50$^{th}$, and 90$^{th}$ quantiles within each porosity unit bin.
- Calculate the Swansons permeability for each porosity bin based upon the quantile values determined in the previous step.
- Plot the average porosity and Swansons permeability with the totality of porosity permeability data as a QA/QC for the transform that has been developed.

With the use of the SPDA core data, the offset Class I core data, and the Swansons means analysis, the porosity and permeability mathematical transforms were able to be developed for the Lower Hosston and Cotton Valley Injection Zones (and internal subzones). The core data available from the SPDA is biased to the reservoir units, which inherently represent the sand facies; meaning the core samples within shale facies of the Lower Hosston and Cotton Valley Formations are sparse and therefore k-phi relationships were built only for the sand facies. The methodology and supporting data for determination of permeability in the shale facies is discussed in *Module B Section 3.3, Table 11*. The equations used to build the permeability property for the Static Model are found in **Figures 3 and 4** and demonstrate the porosity versus permeability plots for each of the injection zones and the range of all core data that was used to derive the Swansons permeability relationships.

With the aim to calibrate the Swanson's porosity permeability transforms; core samples were collected and analyzed from the Texas BEG. Within the BEG core warehouse there was one well available which had core for the Hosston interval, The Bishop No. 1 (API No. 03-139-03544-

0000). The subsurface team at Geostock Sandia LLC and Lapis Energy viewed this core at the BEG and selected a total of seven locations to plug for further analysis on the correlative injection interval sand from the lower Hosston. A range of tests were run on these plugs to aid in the modeling and reduce uncertainties around the reservoir parameters and extent of the plume. For each of these samples Mercury Injection Capillary Pressure tests were done to determine both porosity and permeability. **Figure 5** shows the lab derived porosity and permeability data for the Hosston and how it fits in relation to the data used to derive the Swansons mean transform. The data fits within the trend used to develop the permeability cube in the Static Model indicating that the porosity and permeability ranges for the Project Blue CCS site are representative. This will be confirmed again with testing performed with the data acquisition for the site which is contained in *"Module D. Pre-Operational Testing Plan."*

**Figures 6 to 11** demonstrate the permeability property cubes and the average permeability maps, which were derived from the Swansons mean analysis and used in the Static Model for the Project Blue CCS Site.

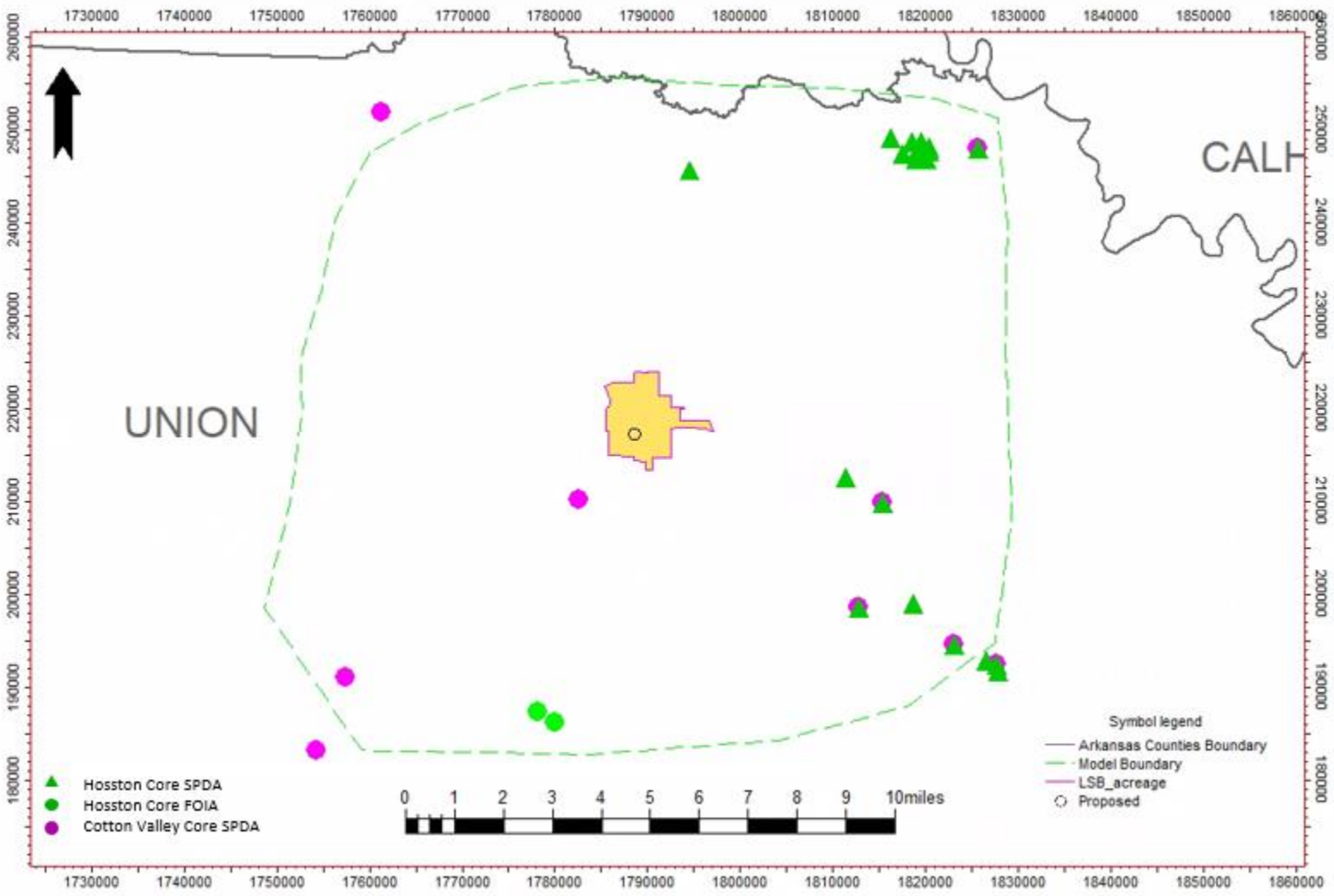


**Figure 1: Location of wells with available core data to build K-Phi relationships for the Static Model.**

| API Number | Well Name | Number of Samples | Depth Range (feet) |
|---|---|---|---|
| **Injection Zone 1 – Lower Hosston** | | | |
| **03-139-00028-0000** | C.A. Langley 1 S | 2 | 3105-3277 |
| **03-139-10119-0000** | Ezzell 27 S | 2 | 3830-4705 |
| **03-139-11038-0000** | Tarver-Ezzell 1 S | 3 | 3263-3268 |
| **03-139-11301-0000** | Craig, H G 1 S | 13 | 3370-4142 |
| **03-139-11455-0000** | Alphin 1 S | 3 | 4138-4142 |
| **03-139-11765-0000** | Craig, H.G 1 S | 11 | 3370-3376 |
| **03-139-11835-0000** | Sandifer 1 S | 8 | 3363-3371 |
| **03-139-12182-0000** | Timmins 1 S | 3 | 3114-3128 |
| **03-139-12255-0000** | Langley 2 S | 11 | 3081-3978 |
| **03-139-12279-0000** | Langley 3 S | 27 | 3040-3809 |
| **03-139-12312-0000** | Williams 1 S | 11 | 3080-3561 |
| **03-139-12337-0000** | Gulf Mineral Fee/Clark 1-7 S | 22 | 3170-3851 |
| **03-139-12361-0000** | Triangle Ind. 2 S | 8 | 3765-4033 |
| **03-139-12529-0000** | Triangle 1 S | 20 | 3286-3693 |
| **03-139-12722-0000** | J.T Murphy 1 S | 5 | 3861-3866 |
| **03-139-12750-0000** | Mitchell Estate 1 S | 14 | 3031-3070 |
| **03-139-12875-0000** | Hinshaw 1 S | 14 | 3391-3619 |
| **03-139-12937-0000** | Waste Disposal Well 5 S | 225 | 3679-5078 |
| **03-139-12938-0000** | Waste Disposal Well 6 S | 97 | 3760-5192 |
| **03-139-13054-0000** | Rosen "B" 1 S | 3 | 3194-3311 |
| **03-139-03544-0000*** | Bishop #1* | 5* | 3929-3954* |
| **Injection Zone 2 – Cotton Valley** | | | |
| **03-139-02271-0000** | Haney 1 S | 5 | 6537-6541 |
| **03-139-03417-0000** | Edson 1S | 32 | 7536-7602 |
| **03-139-10119-0000** | Ezzell 27 S | 22 | 5004-5960 |
| **03-139-11166-0000** | Hogg, James 1 S | 34 | 5365-6878 |
| **03-139-11455-0000** | Alphin 1 S | 1 | 6573 |
| **03-139-11502-0000** | Mekins, Franklin F 1 S | 1 | 5147 |
| **03-139-11765-0000** | Craig, H.G 1 S | 14 | 4138-6030 |
| **03-139-11766-0000** | Clark, O.B 1 S | 6 | 4333-4359 |
| **03-139-13054-0000** | Rosen "B" 1 S | 16 | 3537-4430 |

**Table 1: Detailed Information for wells used to develop K-phi relationships for the Static Model identified in Figure 1.**

***Bishop No. 1 was selected for testing by Geostock and Lapis to calibrate SPDA offset core data in the Lower Hosston Injection Zone***

| Core Porosity (ϕ) Data | |
|---|---|
| Min | 13.0 |
| Max | 31.6 |

Step 1: Min and Max Porosity

Step 4: Calculate Permeability Values For the 10th, 50th, and 90th quantile w Within each Porosity Bin

Step 5: Calculate Swansons Permeability for each Bin

| Bin Number | Min ϕ | Max ϕ | Average ϕ | Permeability 10th | Permeability 50th | Permeability 90th | Swansons Permeability |
|---|---|---|---|---|---|---|---|
| 1 | 13.0 | 15.0 | 13.97 | 0.03 | 0.45 | 6.462 | 2.1276 |
| 2 | 15.0 | 17.0 | 16.04 | 0.386 | 2.3 | 29 | 9.7358 |
| 3 | 17.0 | 19.0 | 18.19 | 0.336 | 21.5 | 278 | 92.1008 |
| 4 | 19.0 | 21.0 | 20.10 | 3.74 | 26.5 | 450.1 | 146.752 |
| 5 | 21.0 | 23.0 | 22.05 | 7.94 | 72 | 795.8 | 269.922 |
| 6 | 23.1 | 25.1 | 24.10 | 32 | 174.5 | 1424.8 | 506.84 |
| 7 | 25.1 | 27.1 | 26.24 | 44 | 194.5 | 820 | 337 |
| 8 | 27.1 | 29.1 | 28.02 | 98.8 | 581 | 1056.9 | 579.11 |
| 9 | 29.1 | 31.1 | 29.91 | 271 | 1000 | 1515.8 | 936.04 |
| 10 | 31.1 | 33.1 | 31.61 | 79.8 | 1171.5 | 4503.1 | 1843.47 |

Step 2: Split data into Porosity Bins @ a 2 p.u interval

Step 3: Calculate Average Porosity In each Bin

**Figure 2: Example Swansons mean data table for porosity bins and permeability transform from the Lower Hosston Formation SPDA core data. This same analysis was performed for the Cotton Valley Formation.**

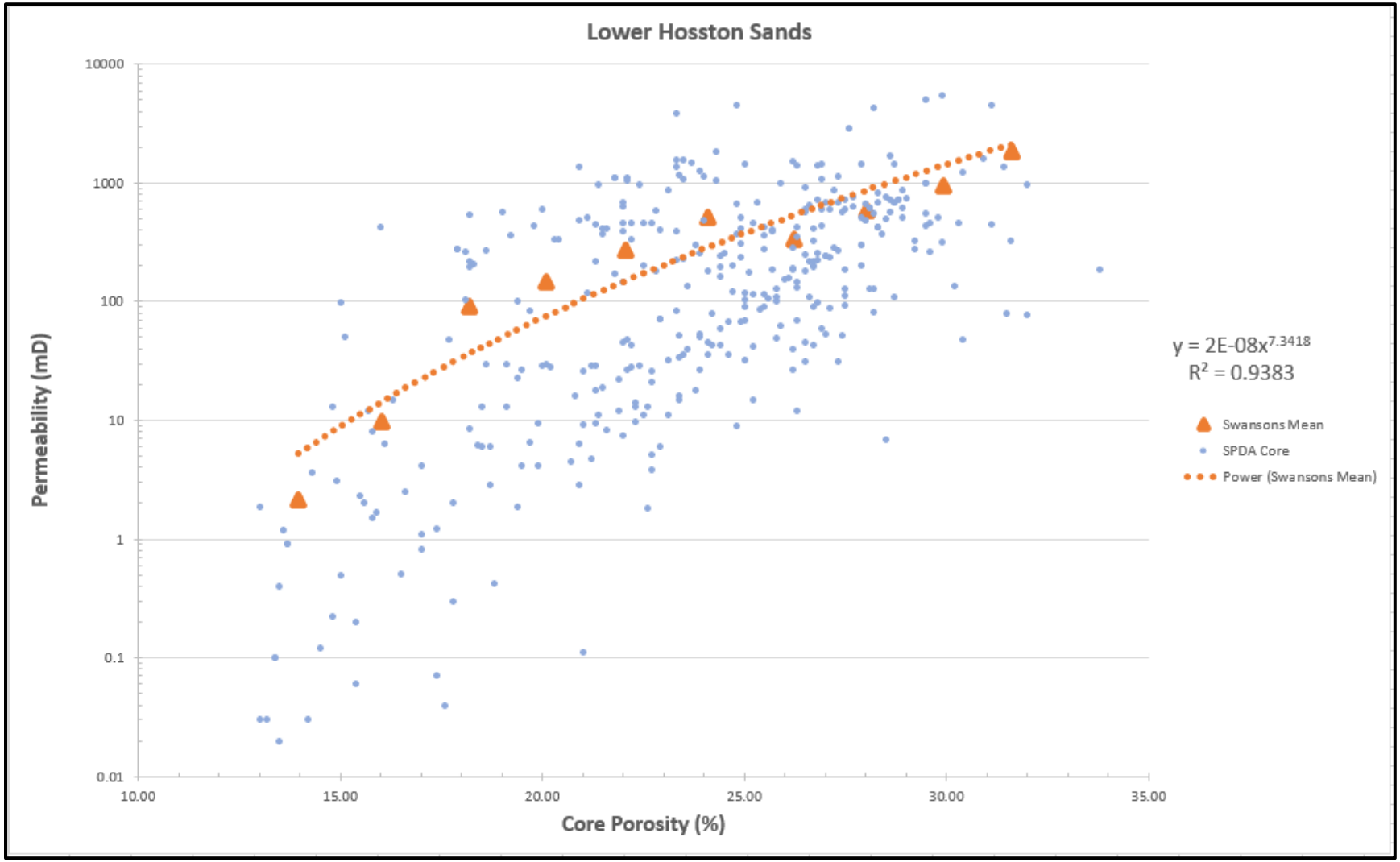


**Figure 3: Swansons mean permeability transform for Lower Hosston Sands**

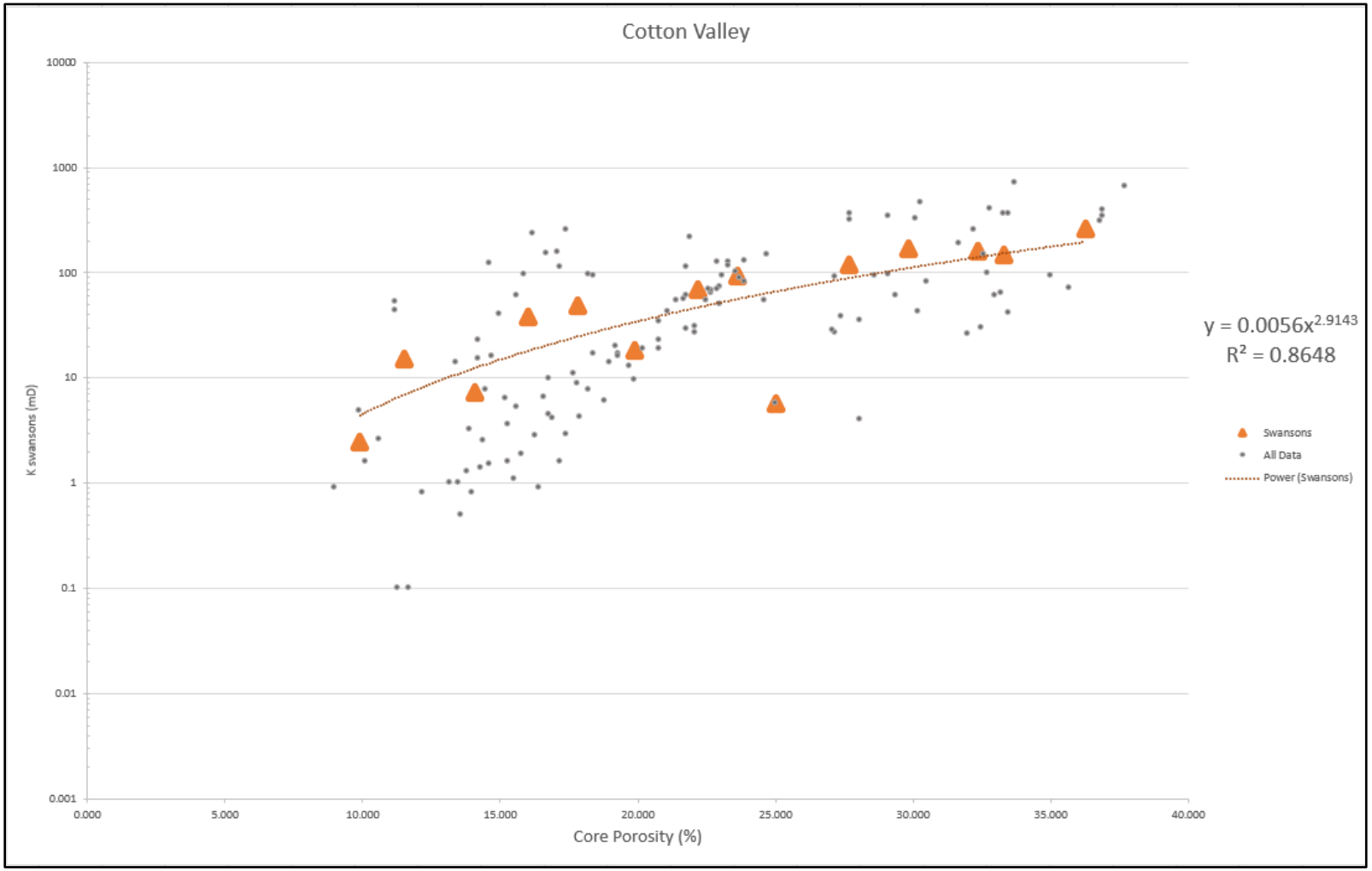


**Figure 4: Swansons mean permeability transform for Cotton Valley Sands**

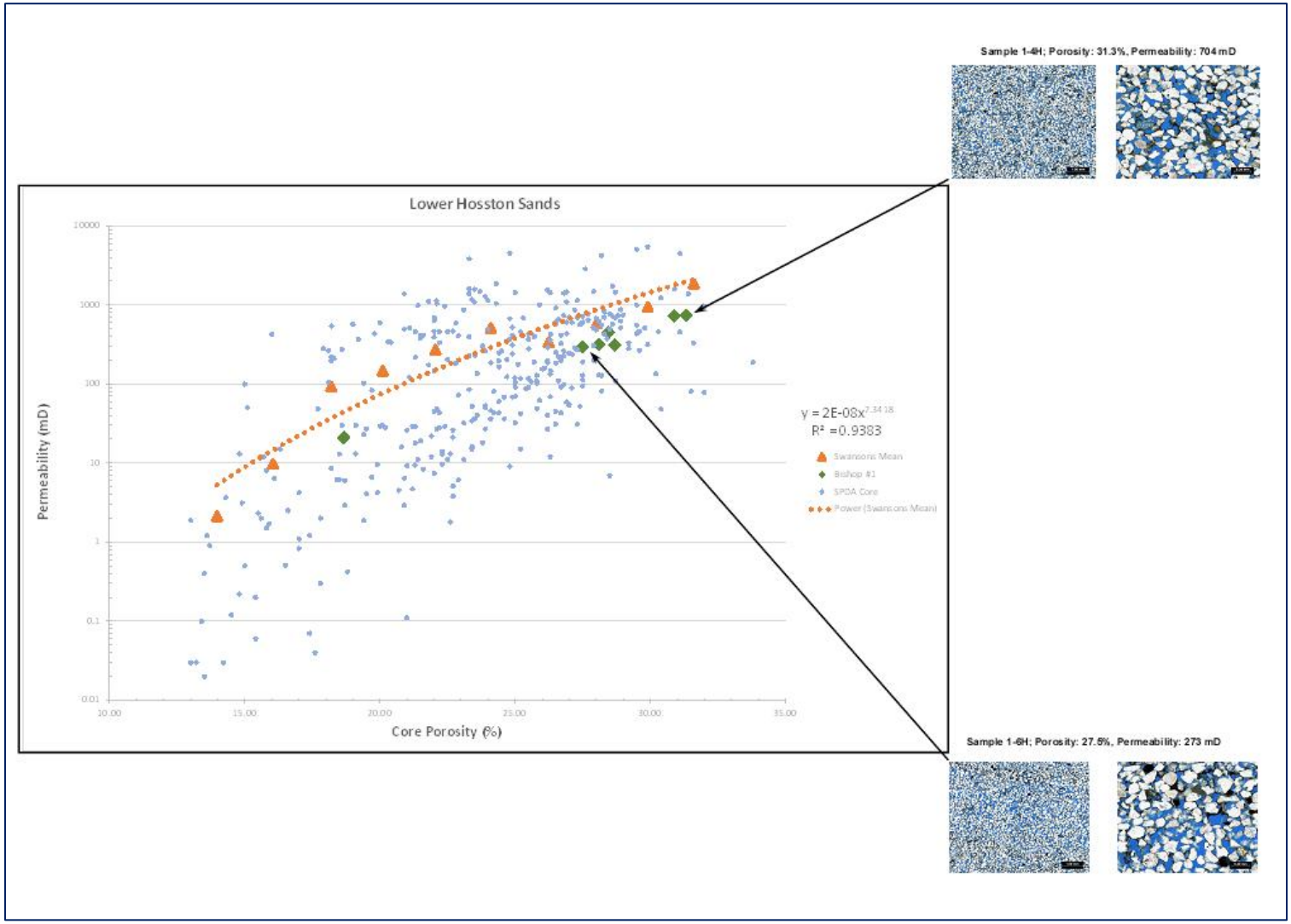


**Figure 5: Porosity and Permeability cross plot with addition of the Bishop No. 1 data for the Lower Hosston Sands. Also pictured are thin sections of the samples selected for the bishop showing the quartz rich grain framework along with the porosity distribution within the Lower Hosston sands.**

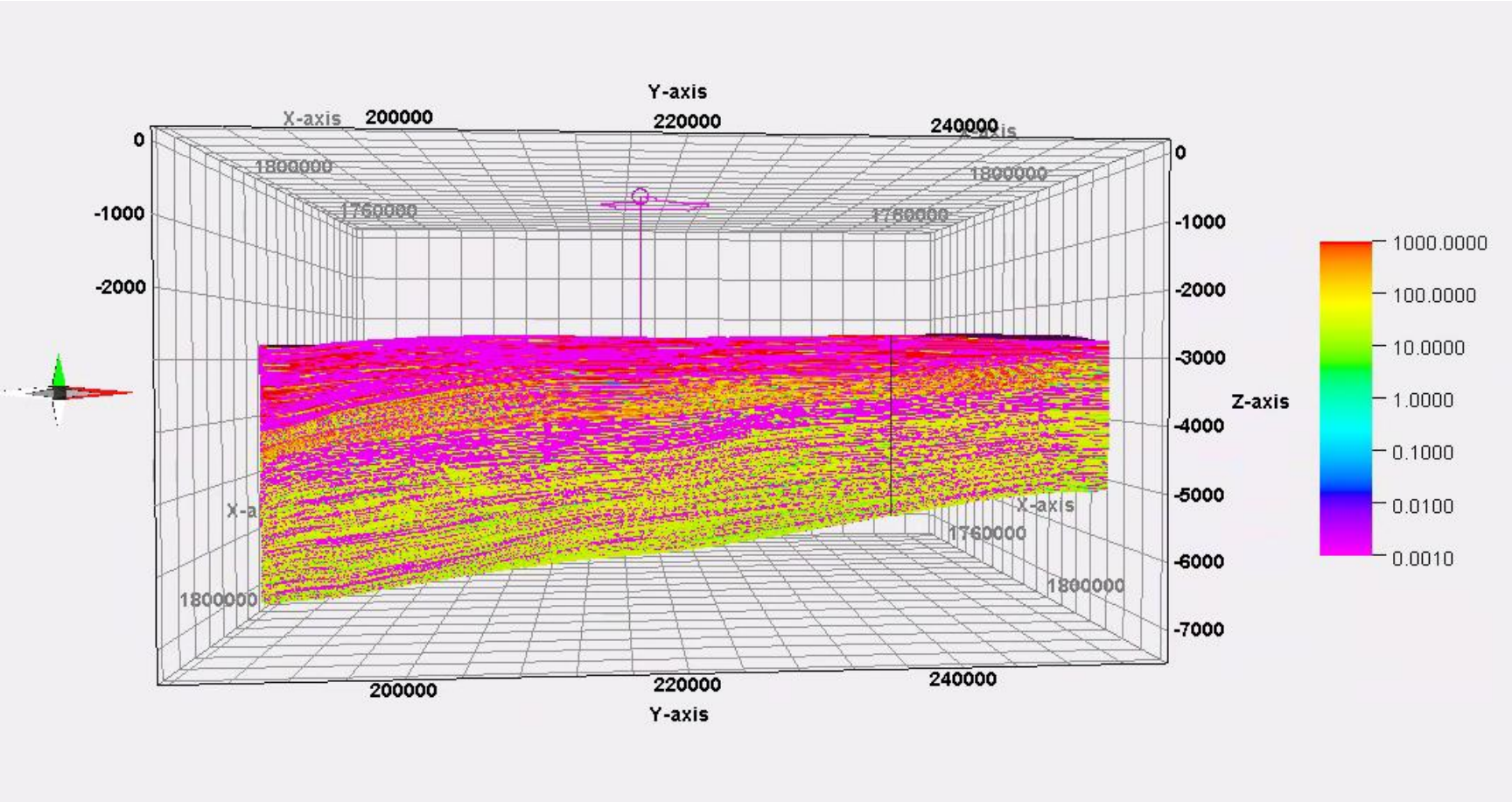


**Figure 6: View looking to the west of the 3D permeability property cube developed utilizing the mathematical transforms described above. This figure is included to help demonstrate the permeability variation between the upper and lower portions of the confinement and injection complex for Project Blue.**

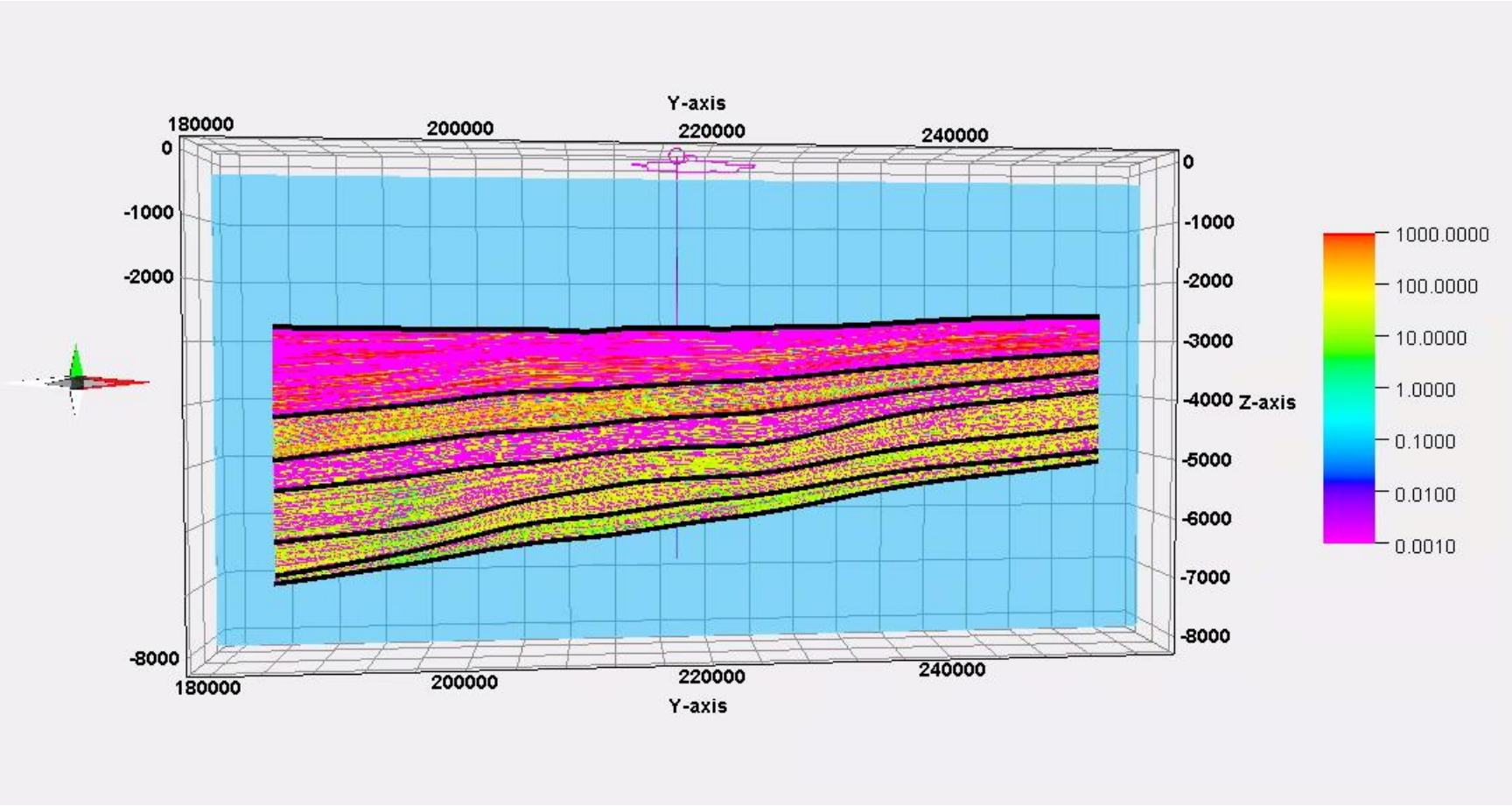


**Figure 7: N-S intersection Visualization of Permeability property through the Project CCS Facility. This figure is included to help demonstrate the permeability variation between the Sand and Shale facies in the upper injection intervals of the model and how this may contribute to the vertical distribution of $CO_2$**

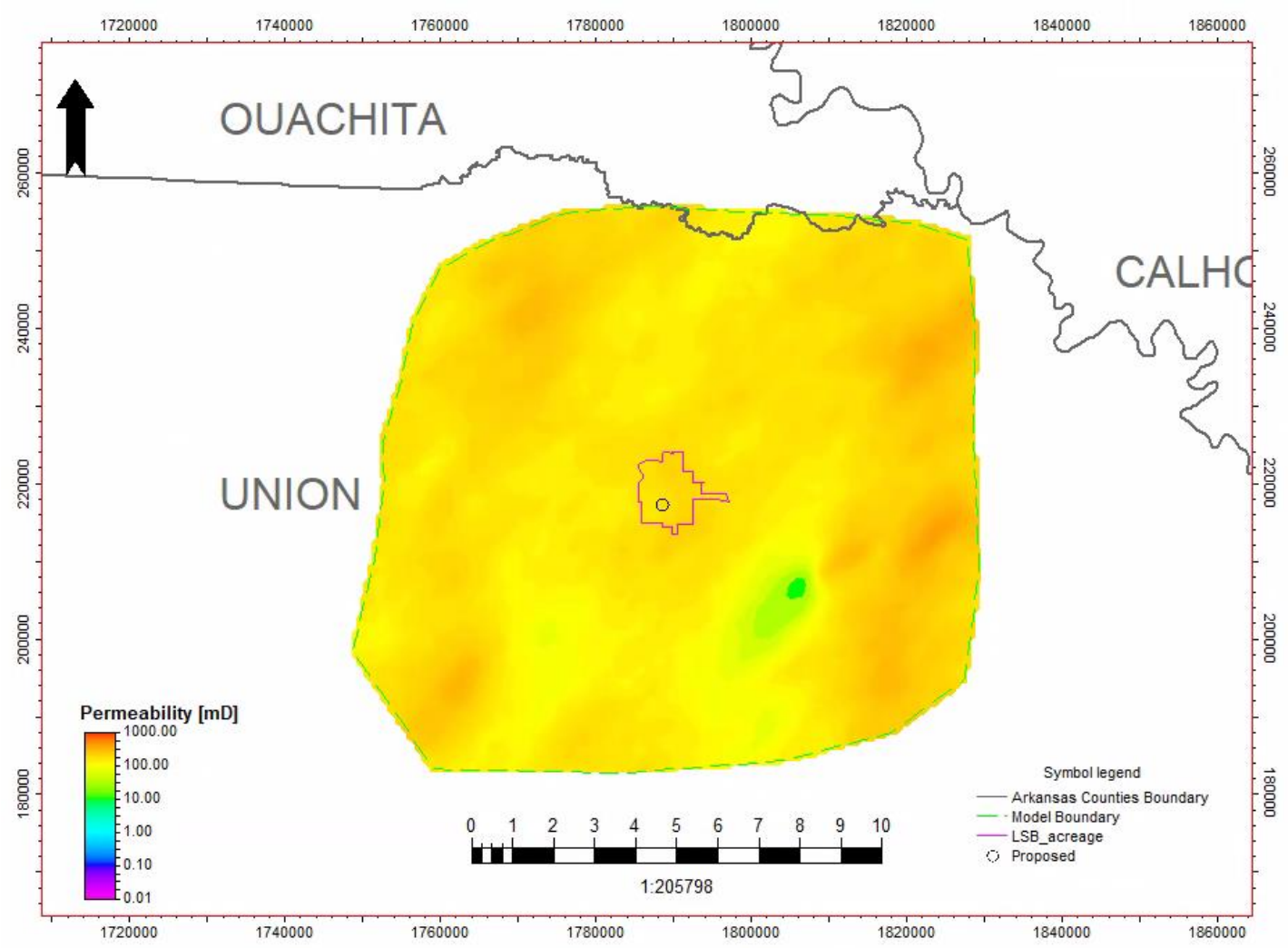


**Figure 8: Average Permeability map for the Lower Hosston Injection Zone**

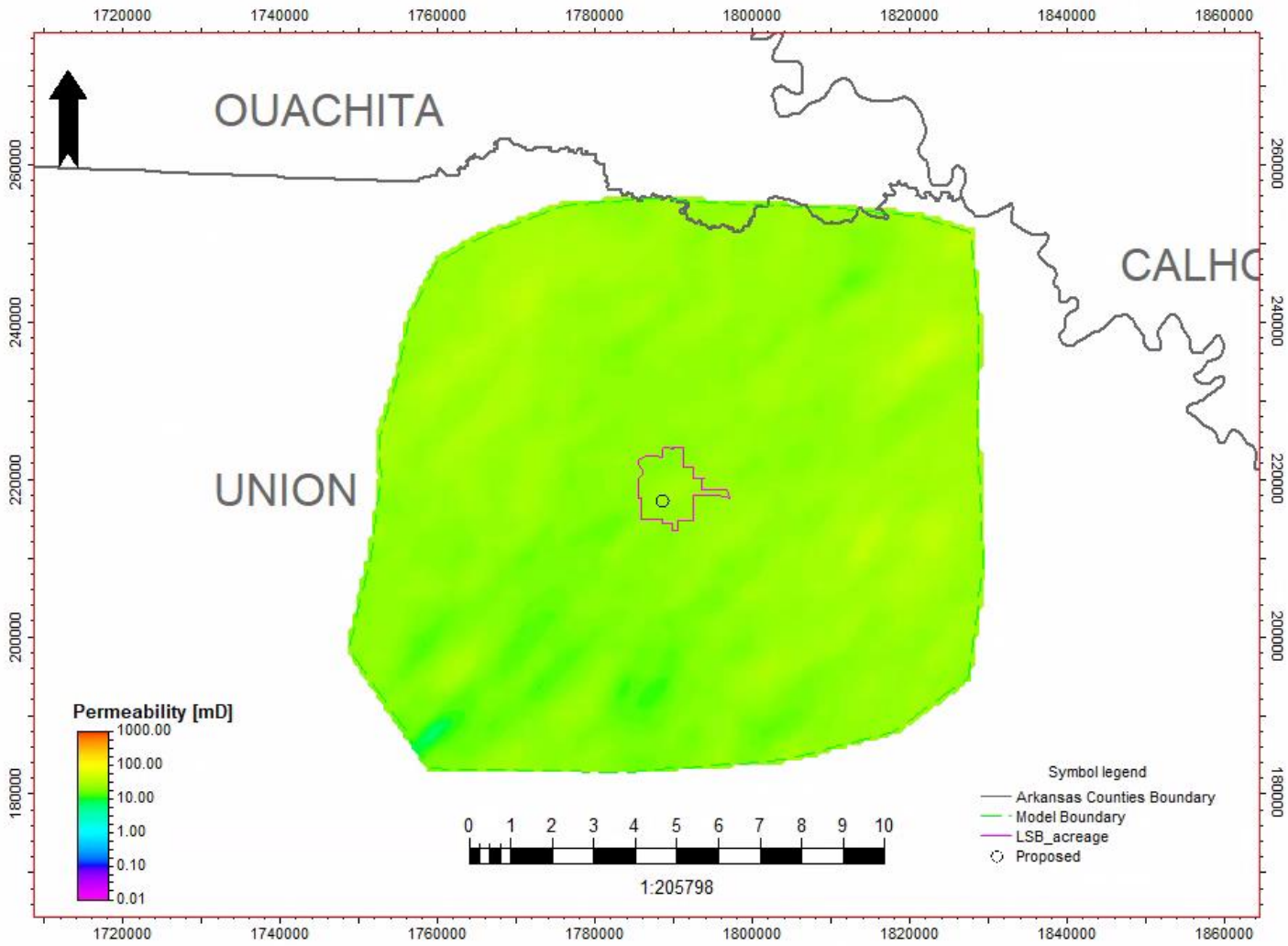


**Figure 9: Average Permeability map for the CV3 interval**

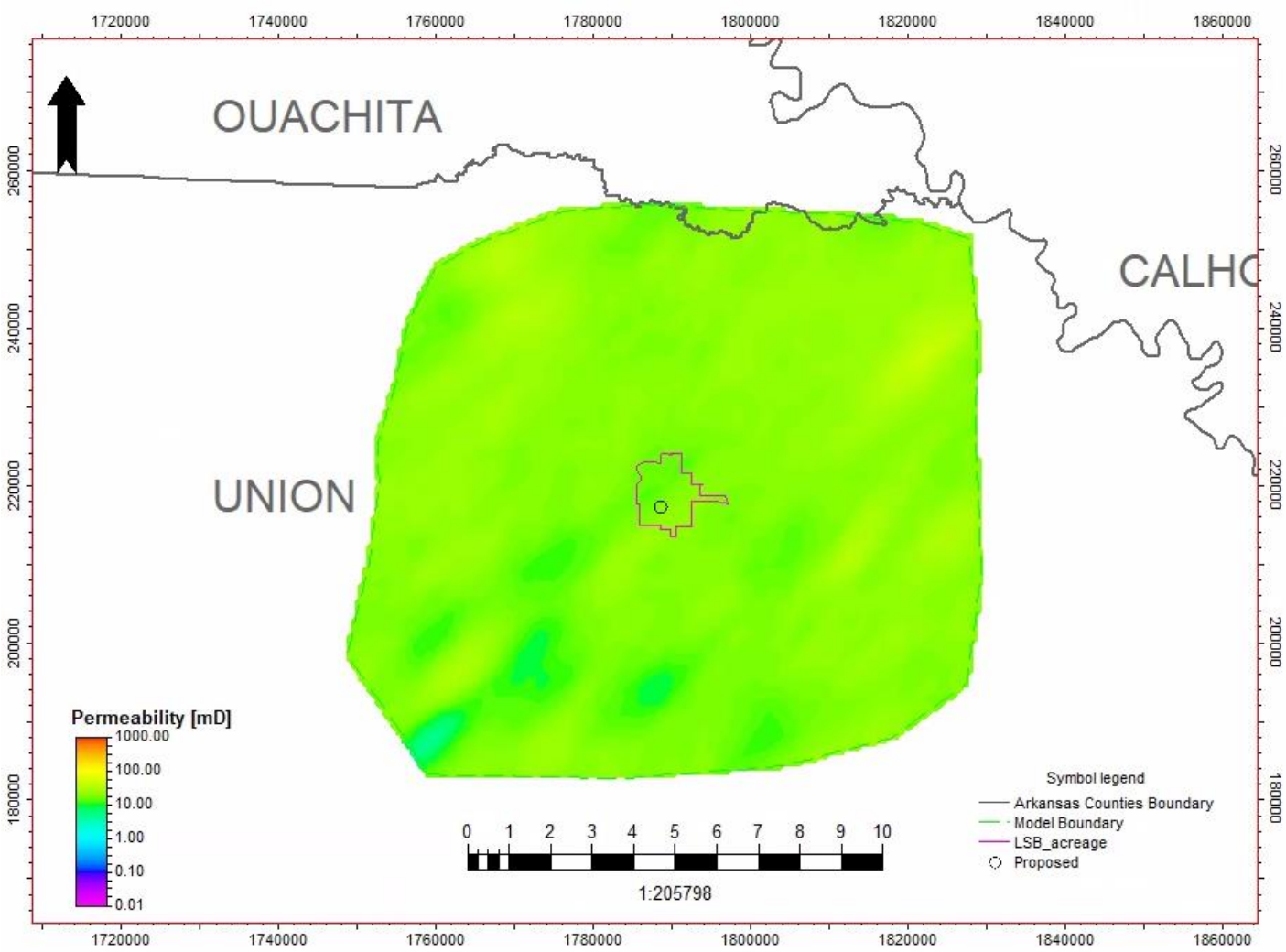


**Figure 10: Average Permeability map for the CV2 interval**

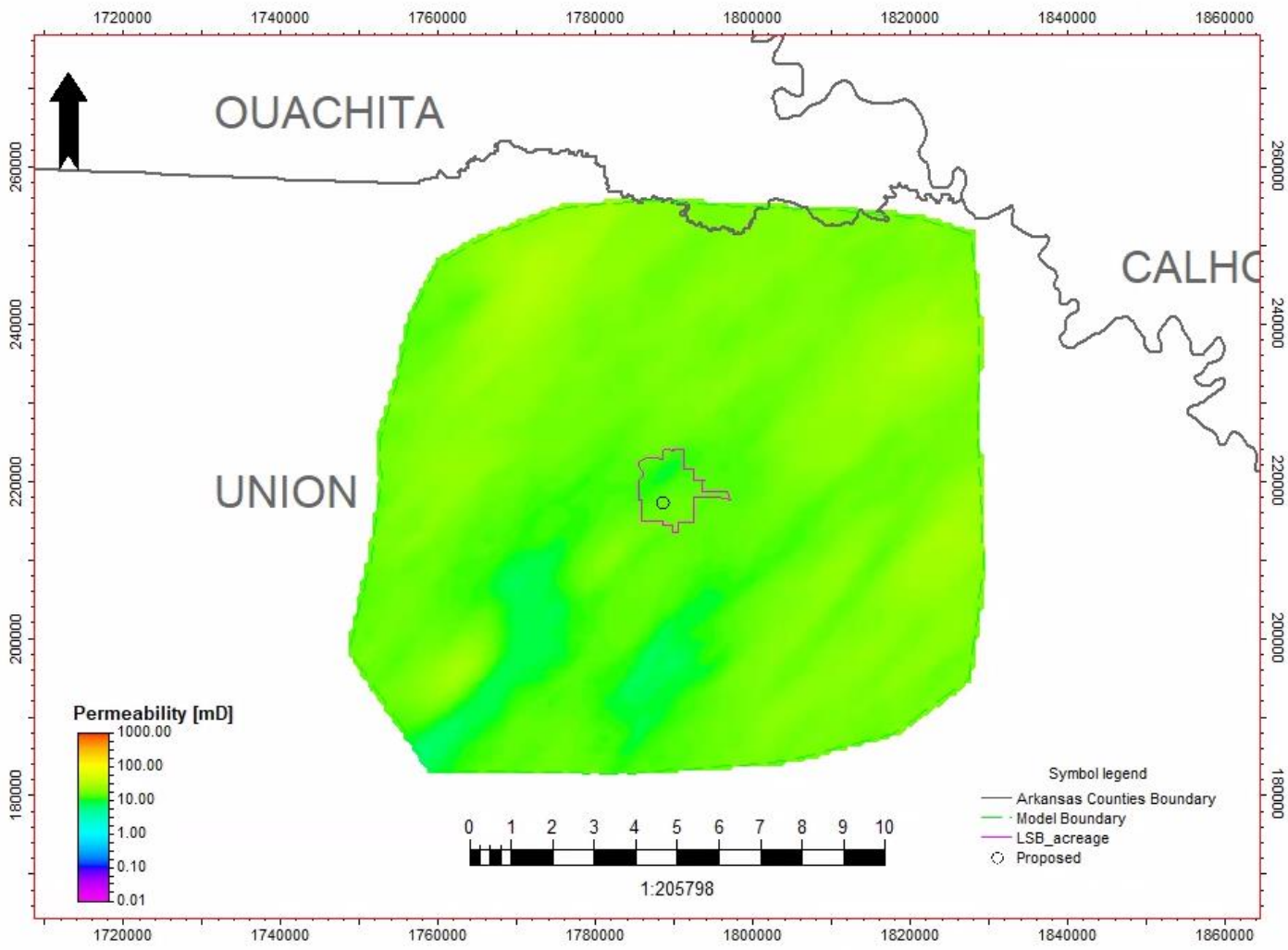


**Figure 11: Average Permeability map for the CV1 interval**