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# 3D Modeling of Lithology and Aquifer Temperature for Development of MODFLOW Calibration Zones

CWEMF 2022 Annual Meeting, Session 22
April 6, 2022

Ralph Simon, P.G., Woodard & Curran
Breanna Clabourne, Woodard & Curran
Reza Namvar, PhD, PE, Woodard & Curran

# Project Background

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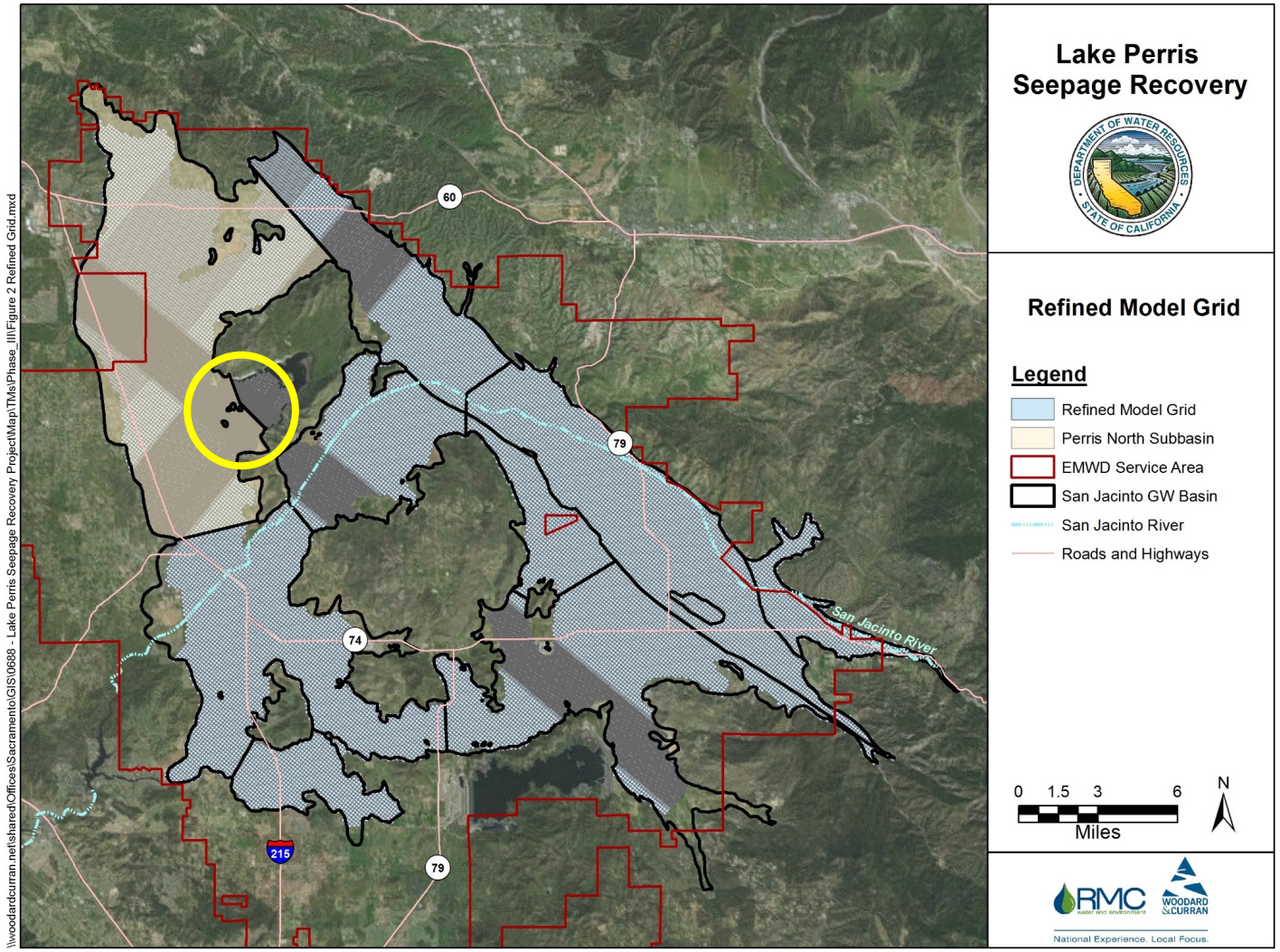
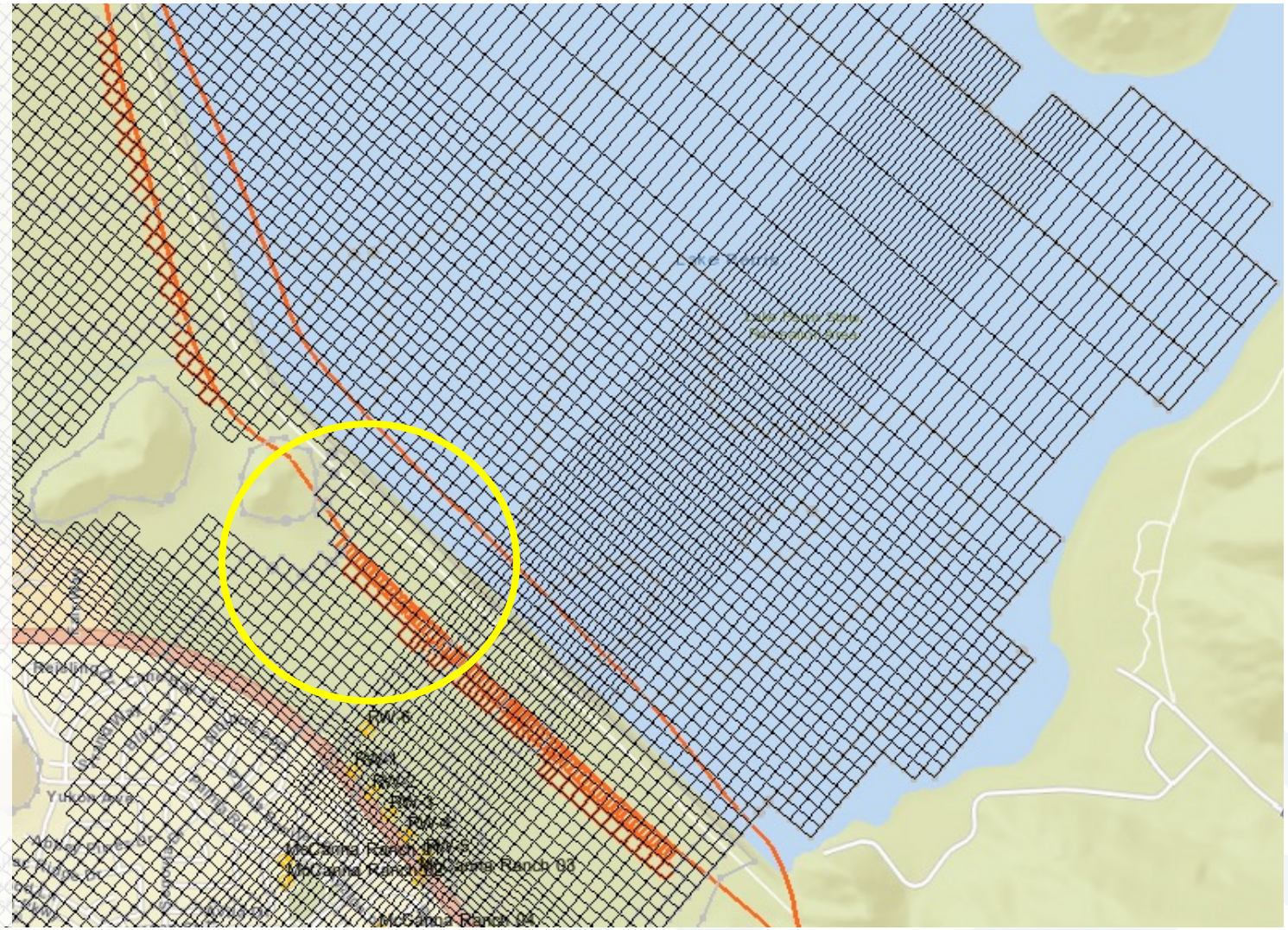
# Objective: Simulate Flow Under the Dam

- Under different scenarios
  - Head
  - Drawdown
  - Velocity
  - Etc.
- Located within existing San Jacinto groundwater basin MODFLOW model



# Conceptual Phases of Modeling Project

- Model Refinement
- Model Calibration & Sensitivity
- Model Runs
- Evaluate Results & Describe Model Construction

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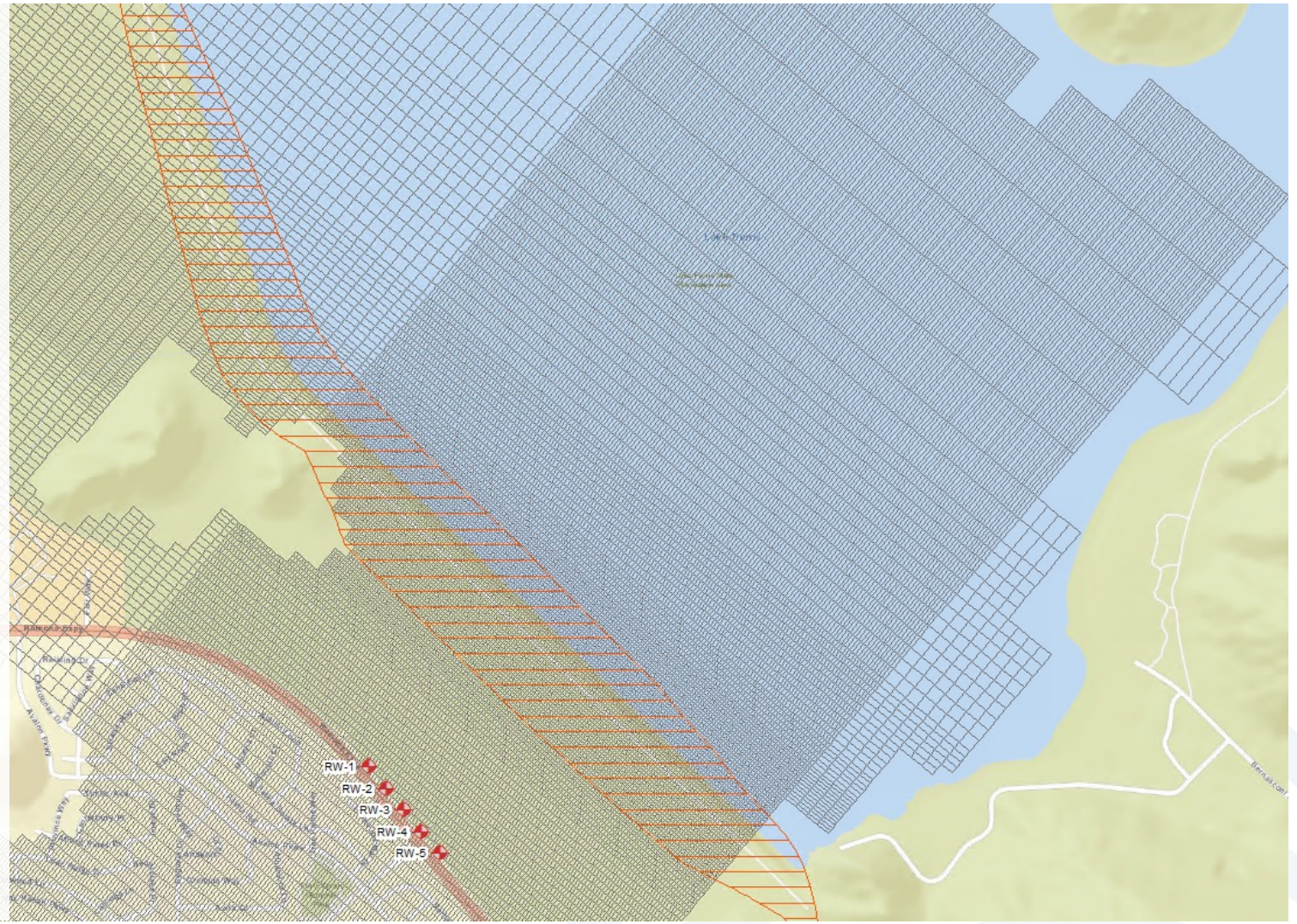
# Conceptual Phases of Modeling Project

- Model Refinement
  - Extract & expand
  - Discretize horizontally & vertically
  - **Establish site-specific K calibration zones based on lithology & aquifer temperature**
- Model Calibration & Sensitivity
- Model Runs
- Evaluate Results & Describe Model Construction

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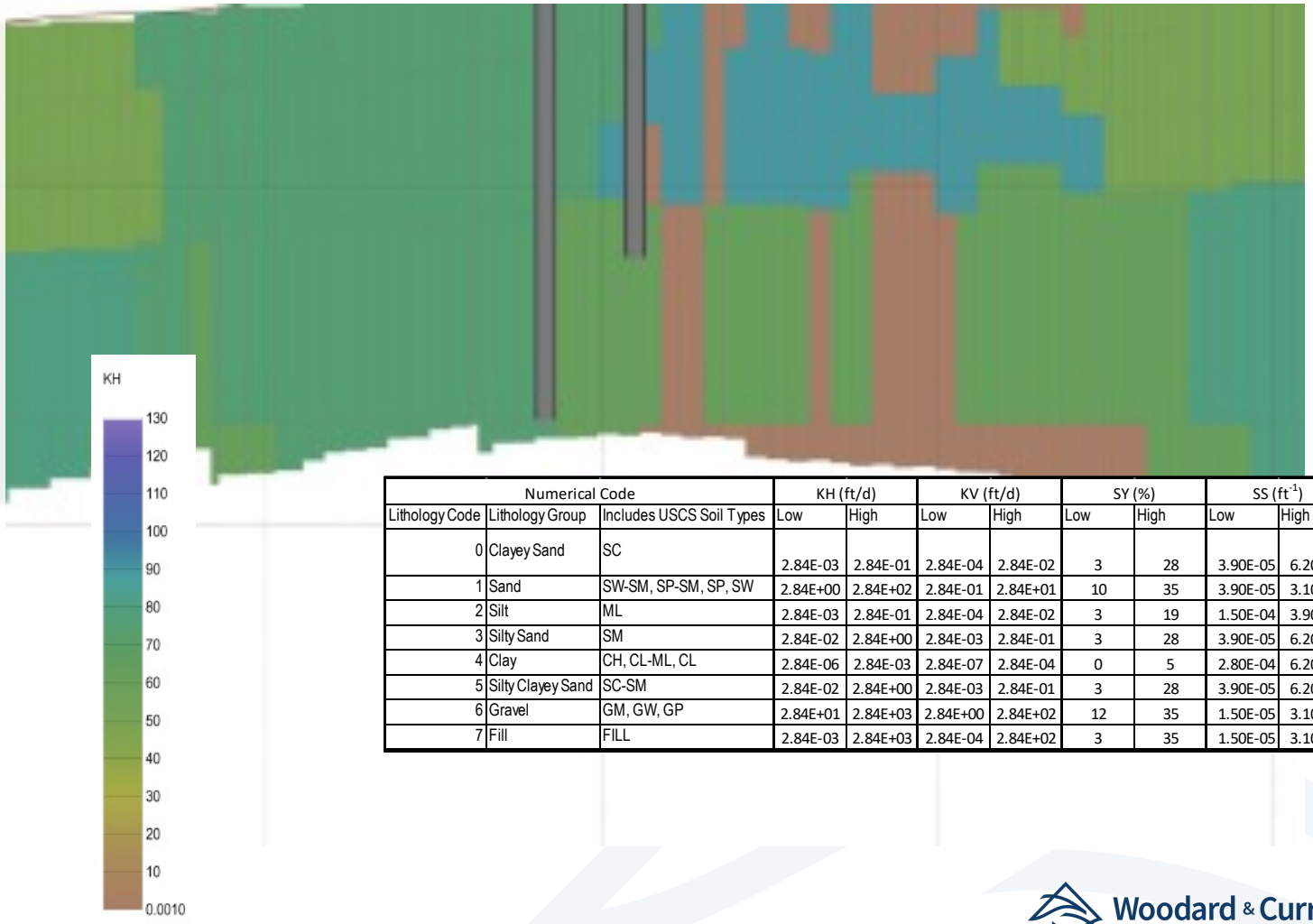
# Conceptual Phases of Modeling Project

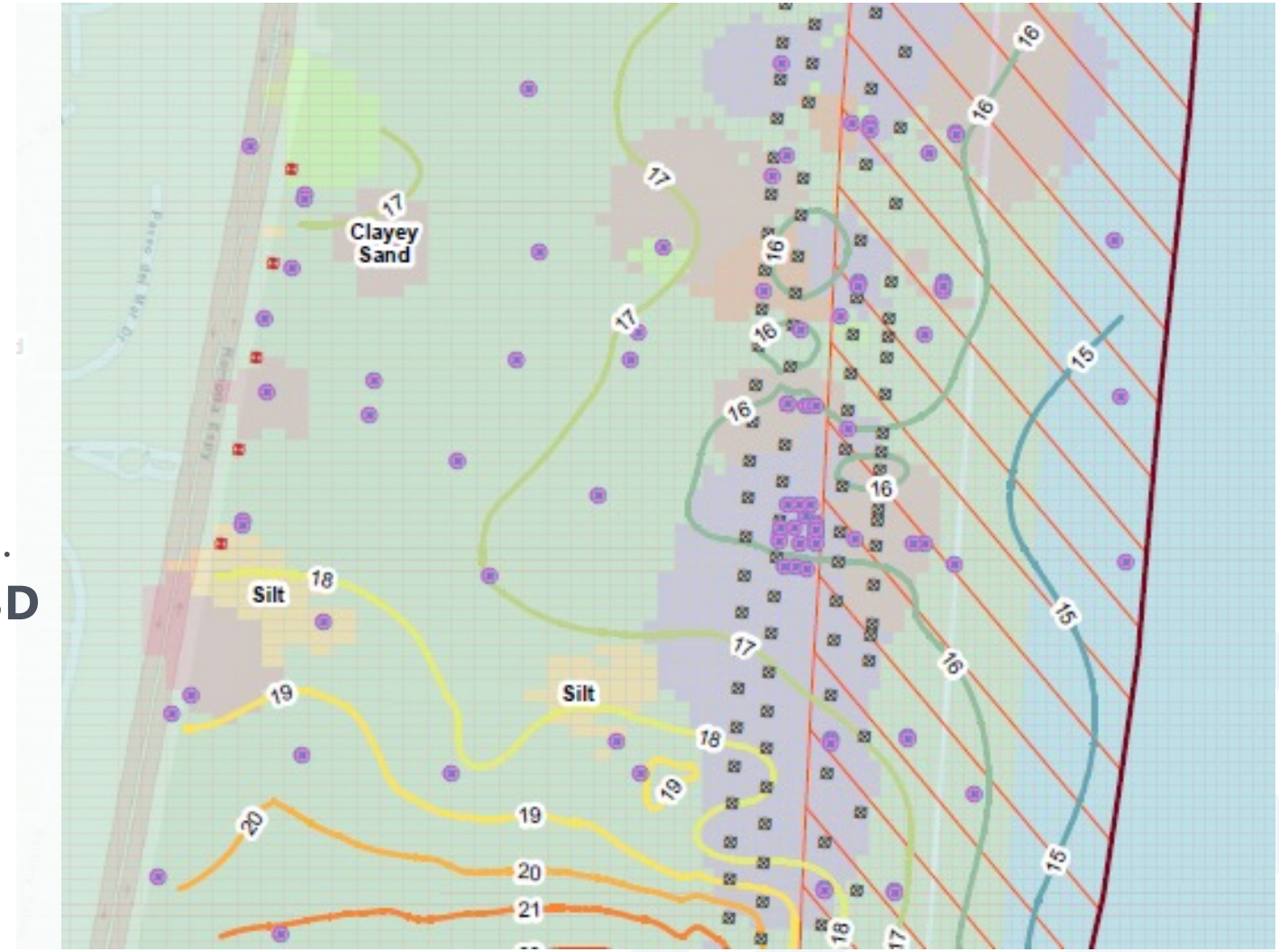
- Model Refinement
- Model Calibration & Sensitivity
  - **Establish initial K based on measured site data**
  - Calibrate model to historical data
  - **Sensitivity analysis**
- Model Runs
- Evaluate Results & Describe Model Construction




| Numerical Code | | | KH (ft/d) | | KV (ft/d) | | SY (%) | | SS ($ft^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lithology Code | Lithology Group | Includes USCS Soil Types | Low | High | Low | High | Low | High | Low | High |
| 0 | Clayey Sand | SC | 2.84E-03 | 2.84E-01 | 2.84E-04 | 2.84E-02 | 3 | 28 | 3.90E-05 | 6.20E-05 |
| 1 | Sand | SW-SM, SP-SM, SP, SW | 2.84E+00 | 2.84E+02 | 2.84E-01 | 2.84E+01 | 10 | 35 | 3.90E-05 | 3.10E-04 |
| 2 | Silt | ML | 2.84E-03 | 2.84E-01 | 2.84E-04 | 2.84E-02 | 3 | 19 | 1.50E-04 | 3.90E-04 |
| 3 | Silty Sand | SM | 2.84E-02 | 2.84E+00 | 2.84E-03 | 2.84E-01 | 3 | 28 | 3.90E-05 | 6.20E-05 |
| 4 | Clay | CH, CL-ML, CL | 2.84E-06 | 2.84E-03 | 2.84E-07 | 2.84E-04 | 0 | 5 | 2.80E-04 | 6.20E-03 |
| 5 | Silty Clayey Sand | SC-SM | 2.84E-02 | 2.84E+00 | 2.84E-03 | 2.84E-01 | 3 | 28 | 3.90E-05 | 6.20E-05 |
| 6 | Gravel | GM, GW, GP | 2.84E+01 | 2.84E+03 | 2.84E+00 | 2.84E+02 | 12 | 35 | 1.50E-05 | 3.10E-05 |
| 7 | Fill | FILL | 2.84E-03 | 2.84E+03 | 2.84E-04 | 2.84E+02 | 3 | 35 | 1.50E-05 | 3.10E-04 |

# Conceptual Phases of Modeling Project

- Model Refinement
- Model Calibration & Sensitivity
- Model Runs
- Evaluate Results & Describe Model Construction
  - Various outputs, tables, etc.
  - **Maps, cross-sections, & 3D visualizations of input & output parameters**

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# EVS (Earth Volumetric Studio) Approach

**C Tech Development Corporation**

Three-dimensional volumetric Earth Science software

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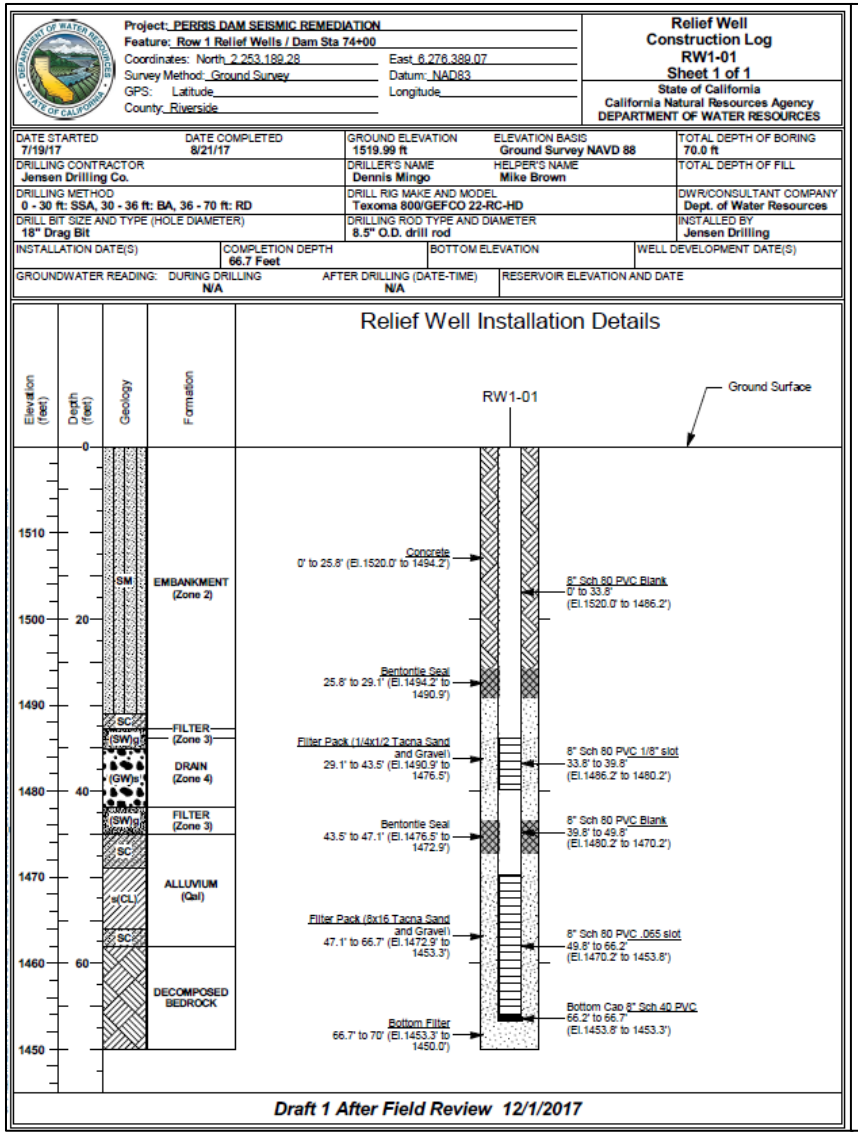
# EVS Approach – Available Data

- Lithology data for 341 boreholes
- Downhole temperature data for 112 wells, monthly, over 2 years



Project: PERRIS DAM SEISMIC REMEDIATION
Feature: Row 1 Relief Wells / Dam Sta 74+00
Coordinates: North 2,253,189.28 East 6,276,389.07
Survey Method: Ground Survey Datum: NAD83
GPS: Latitude Longitude
County: Riverside

Relief Well Construction Log
RW1-01
Sheet 1 of 1
State of California
California Natural Resources Agency
DEPARTMENT OF WATER RESOURCES

| | | | |
|---|---|---|---|
| DATE STARTED 7/19/17 | DATE COMPLETED 8/21/17 | GROUND ELEVATION 1519.99 ft | ELEVATION BASIS Ground Survey NAVD 88 |
| TOTAL DEPTH OF BORING 70.0 ft | | | |
| DRILLING CONTRACTOR Jensen Drilling Co. | | DRILLER'S NAME Dennis Mingo | HELPER'S NAME Mike Brown |
| TOTAL DEPTH OF FILL | | | |
| DRILLING METHOD 0 - 30 ft: SSA, 30 - 36 ft: BA, 36 - 70 ft: RD | | DRILL RIG MAKE AND MODEL Texoma 800/GEFCO 22-RC-HD | |
| DWR/CONSULTANT COMPANY Dept. of Water Resources | | | |
| DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 18" Drag Bit | | DRILLING ROD TYPE AND DIAMETER 8.5" O.D. drill rod | |
| INSTALLED BY Jensen Drilling | | | |
| INSTALLATION DATE(S) | COMPLETION DEPTH 66.7 Feet | BOTTOM ELEVATION | WELL DEVELOPMENT DATE(S) |
| GROUNDWATER READING: DURING DRILLING N/A | AFTER DRILLING (DATE-TIME) N/A | RESERVOIR ELEVATION AND DATE | |



*Draft 1 After Field Review 12/1/2017*

**Observation Well OW-103**

| Depth (ft bgs) | Elevation (ft) | 9/27/2016 Temp (°C) | 12/8/2016 Temp (°C) | 2/10/2017 Temp (°C) | 3/9/2017 Temp (°C) | 4/6/2017 Temp (°C) |
|---|---|---|---|---|---|---|
| 22 | 1454.83 | 21.55 | 22.24 | 22.07 | 21.84 | 21.54 |
| 24 | 1452.83 | 21.28 | 21.99 | 22.05 | 21.82 | 21.63 |
| 26 | 1450.83 | 21.13 | 21.82 | 22.02 | 21.83 | 21.65 |
| 28 | 1448.83 | 21.07 | 21.69 | 21.96 | 21.84 | 21.69 |
| 30 | 1446.83 | 21.06 | 21.59 | 21.89 | 21.83 | 21.70 |
| 32 | 1444.83 | 21.08 | 21.51 | 21.83 | 21.81 | 21.72 |
| 34 | 1442.83 | 21.12 | 21.49 | 21.77 | 21.78 | 21.72 |
| 36 | 1440.83 | 21.14 | 21.47 | 21.67 | 21.71 | 21.72 |
| 38 | 1438.83 | 21.20 | 21.48 | 21.63 | 21.66 | 21.70 |
| 40 | 1436.83 | 21.26 | 21.49 | 21.61 | 21.62 | 21.68 |
| 42 | 1434.83 | 21.29 | 21.48 | 21.59 | 21.61 | 21.66 |
| 44 | 1432.83 | 21.34 | 21.49 | 21.58 | 21.59 | 21.64 |
| 46 | 1430.83 | 21.37 | 21.50 | 21.56 | 21.57 | 21.63 |
| 48 | 1428.83 | 21.39 | 21.51 | 21.56 | 21.56 | 21.61 |
| 50 | 1426.83 | 21.41 | 21.52 | 21.55 | 21.55 | 21.60 |
| 52.27 | 1424.56 | 21.44 | 21.54 | 21.55 | 21.55 | 21.59 |

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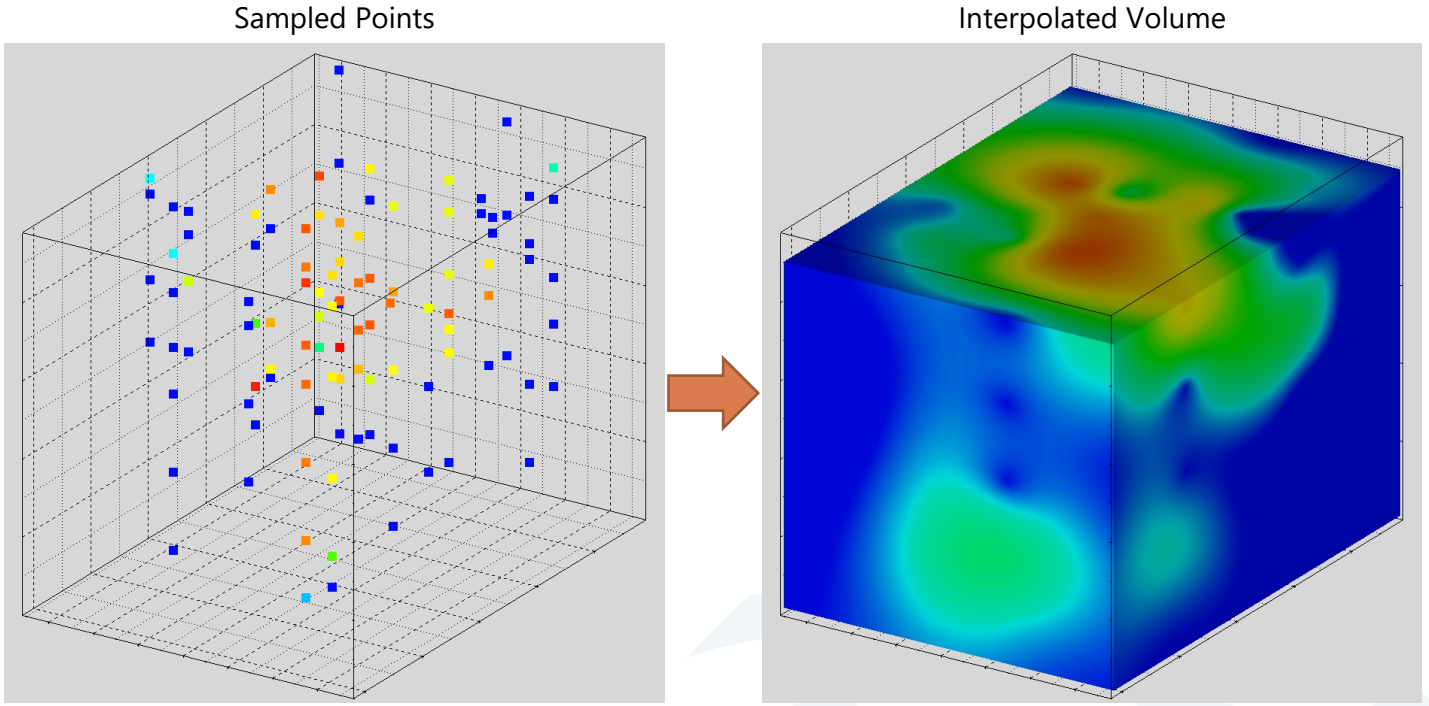
# EVS Approach – Overview (Calibration Zones)

- Use interpolation to estimate lithology types & aquifer temperature at all locations in 3D space
- Assign lithology type & temperature to each MODFLOW cell based on values at the cell centroid
  - Lithology types become zones
  - Temperature classified manually into A and B subzones




https://innolitics.com/portfolio/natural-neighbor/

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# EVS Approach – Lithology Model

- Simplified lithology descriptions to fit in 8 generalized categories

| DWR | | W&C | |
|---|---|---|---|
| Group Symbol | Group Name | Lithology Code | Lithology Group |
| FILL | Fill | 7 | Fill |
| CH | FAT CLAY | 4 | Clay |
| CL-ML | SANDY SILTY CLAY | 4 | Clay |
| CL | SANDY LEAN CLAY | 4 | Clay |
| ML | SILT | 2 | Silt |
| SC | CLAYEY SAND | 0 | Clayey Sand |
| SC-SM | SILTY CLAYEY SAND | 5 | Silty Clayey Sand |
| SM | SILTY SAND | 3 | Silty Sand |
| SW-SC | Well-Graded SAND with Clay | 1 | Sand |
| SP-SC | Poorly Graded SAND with Clay | 1 | Sand |
| SW-SM | Well-Graded SAND with Silt | 1 | Sand |
| SP-SM | Poorly Graded SAND with Silt | 1 | Sand |
| SP | Poorly Graded SAND | 1 | Sand |
| SW | SILTY SAND with Gravel | 1 | Sand |
| GM | SILTY GRAVEL | 6 | Gravel |
| GW | Well-Graded GRAVEL with Sand | 6 | Gravel |
| GP | Poorly Graded GRAVEL | 6 | Gravel |

# EVS Approach – Lithology Model

- Simplified lithology descriptions to fit in 8 generalized categories
- Generate EVS input (.LSDV) file

| DWR | | W&C | |
|---|---|---|---|
| Group Symbol | Group Name | Lithology Code | Lithology Group |
| FILL | Fill | 7 | Fill |
| CH | FAT CLAY | 4 | Clay |
| CL-ML | SANDY SILTY CLAY | 4 | Clay |
| CL | SANDY LEAN CLAY | 4 | Clay |
| | | 2 | Silt |
| | | 0 | Clayey Sand |
| | | 5 | Silty Clayey Sand |
| | | 3 | Silty Sand |
| | ith Clay | 1 | Sand |
| | with Clay | 1 | Sand |
| | ith Silt | 1 | Sand |
| | with Silt | 1 | Sand |
| | | 1 | Sand |
| | el | 1 | Sand |
| | | 6 | Gravel |
| | with Sand | 6 | Gravel |
| | L | 6 | Gravel |

```
# C Tech Data Exporter generated LSDV File from DWR Lithology 2021.05.05.XLSX (05/05/2021 9:42)
Depth "4|Clay" "2|Silt" "0|Clayey Sand" "5|Silty Clayey Sand" "3|Silty Sand" "1|Sand" "6|Gravel" "7|Fill" ft
# Columns [LSDV]: "X" "Y" "Depth" "X" "Y" "Bottom" "Lithology_Group" "PointID" "Corrected_Elev"
6280566.288,2250313.457,6.0,6280566.288,2250313.457,7,0,A-1,1608
6280566.288,2250313.457,7.0,6280566.288,2250313.457,7.85,0,A-1,1608
6280566.288,2250313.457,7.9,6280566.288,2250313.457,13.3,0,A-1,1608
6280566.288,2250313.457,13.3,6280566.288,2250313.457,13.8,1,A-1,1608
6280566.288,2250313.457,13.8,6280566.288,2250313.457,17.7,0,A-1,1608
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6277659.661,2251708.167,2.5,6277659.661,2251708.167,5.5,2,B-1,1481.913
6277659.661,2251708.167,5.5,6277659.661,2251708.167,22,0,B-1,1481.913
```

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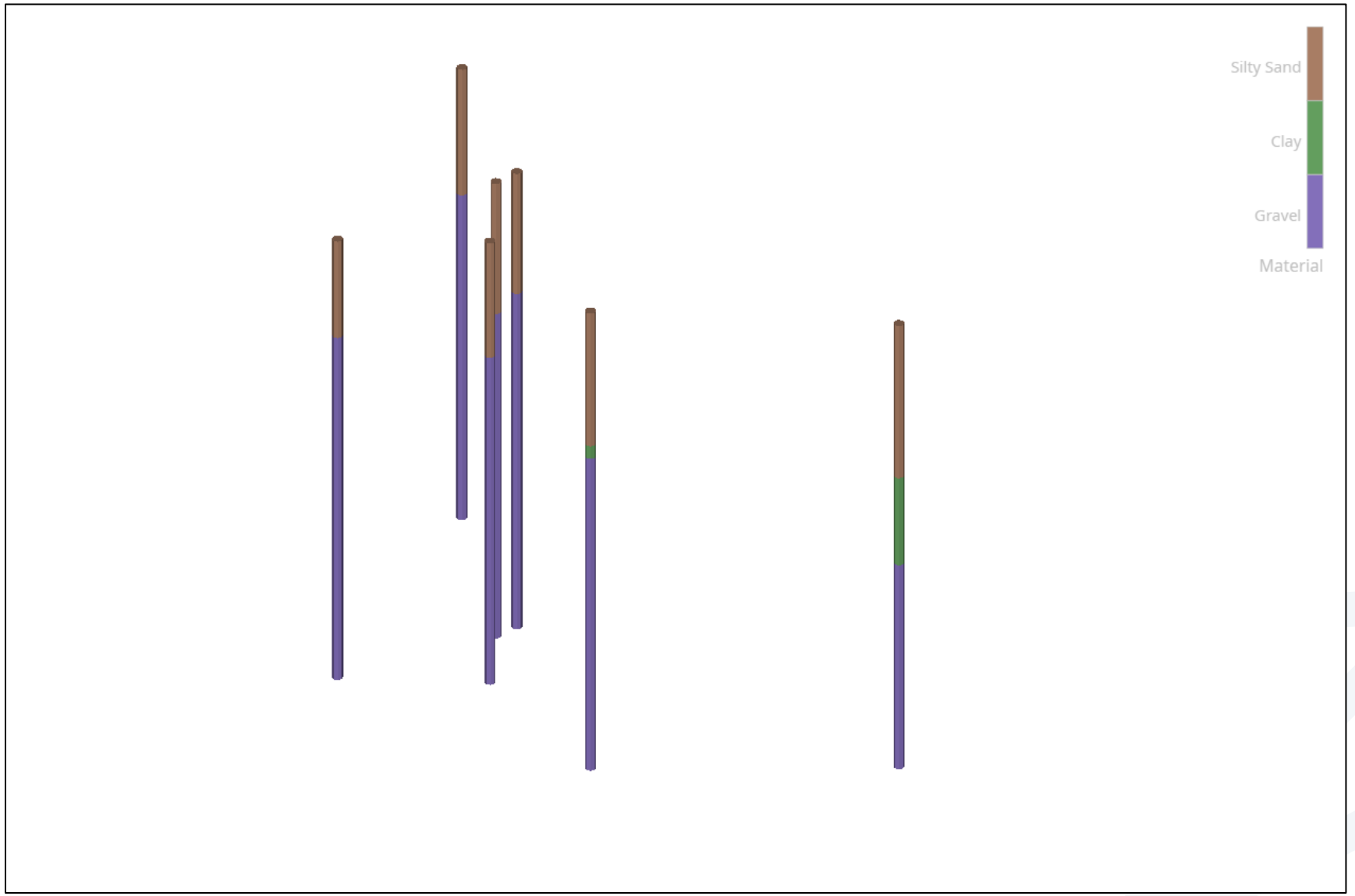
# EVS Approach – Lithology Kriging

- Adaptive Indicator krig module
  - Kriging of each lithology to determine probability at each node in a 3D grid
  - Lithology with highest probability at a node location is assigned to the node
  - Grid is split to create smooth boundaries surrounding areas of same lithology

# EVS Approach – Indicator Kriging

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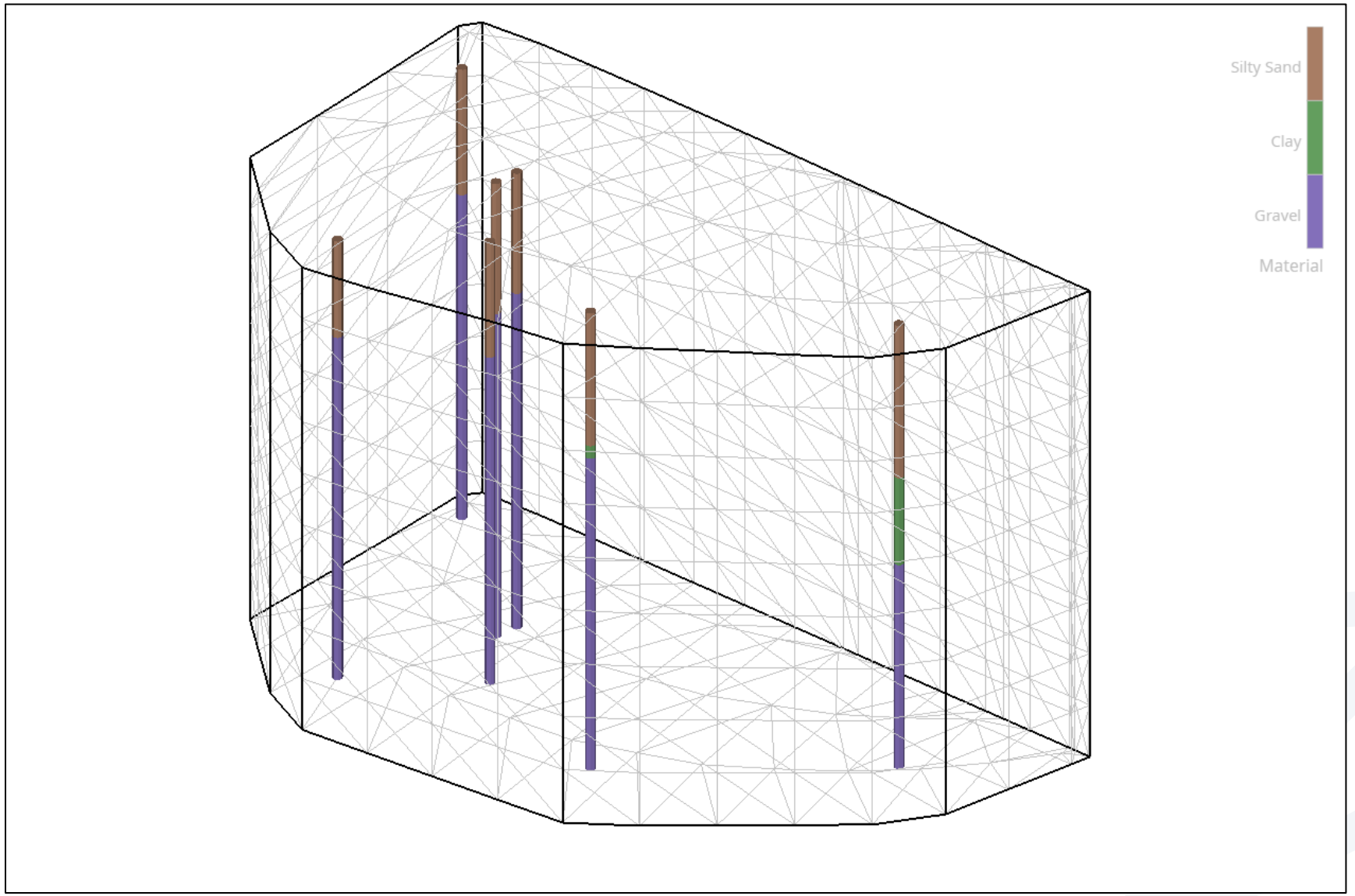
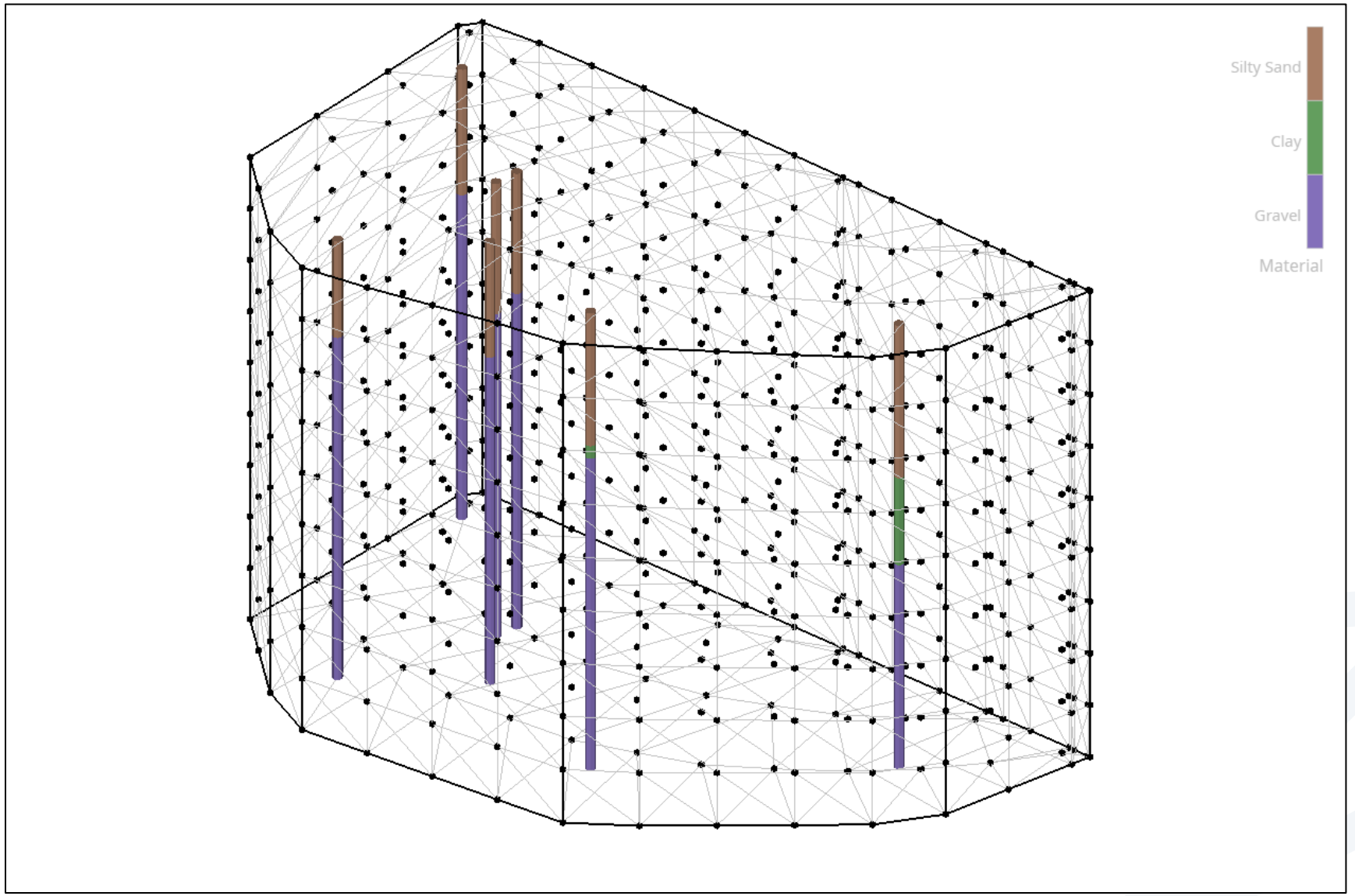
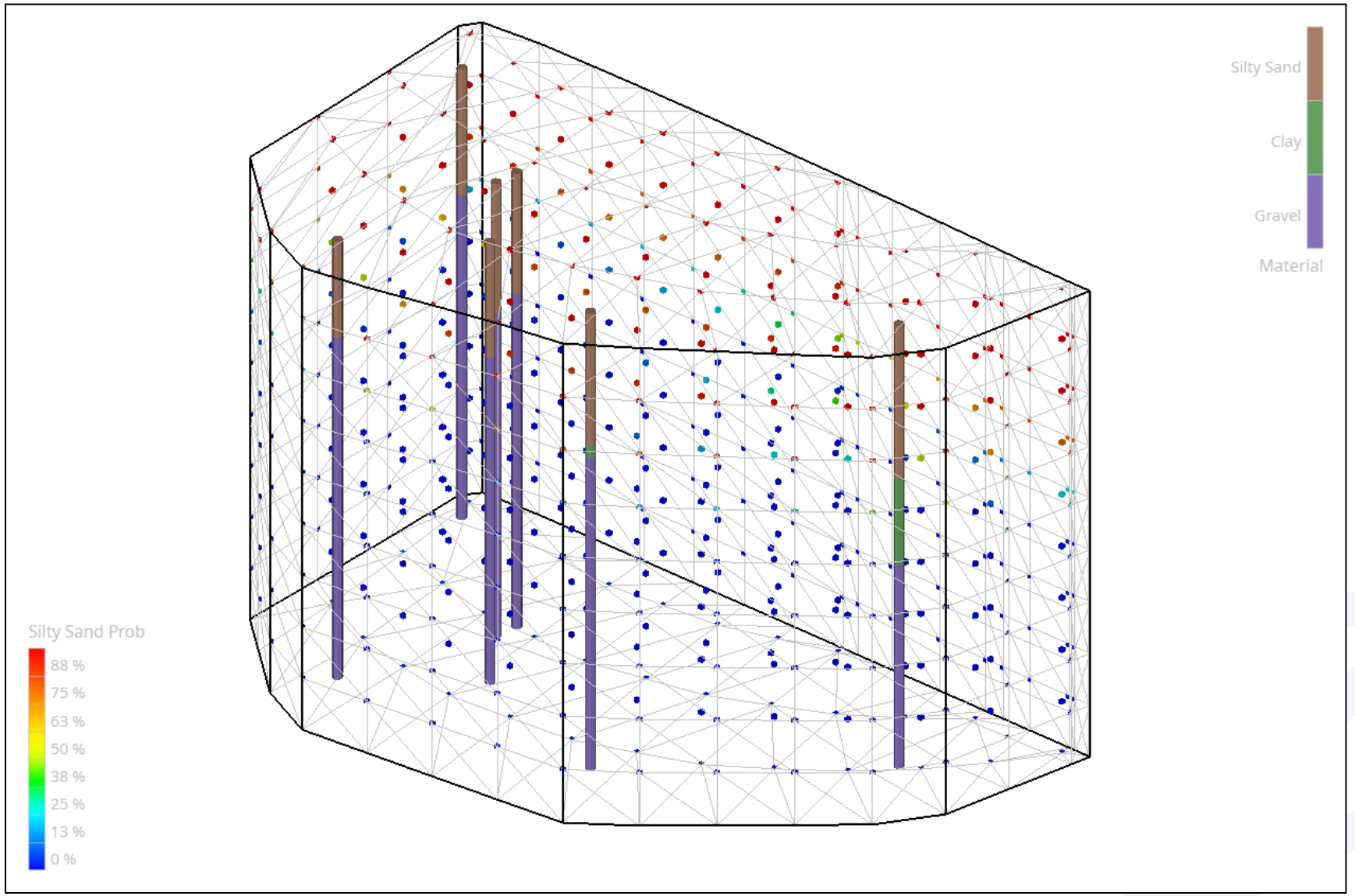
# EVS Approach – Indicator Kriging



# EVS Approach – Indicator Kriging



# EVS Approach – Indicator Kriging

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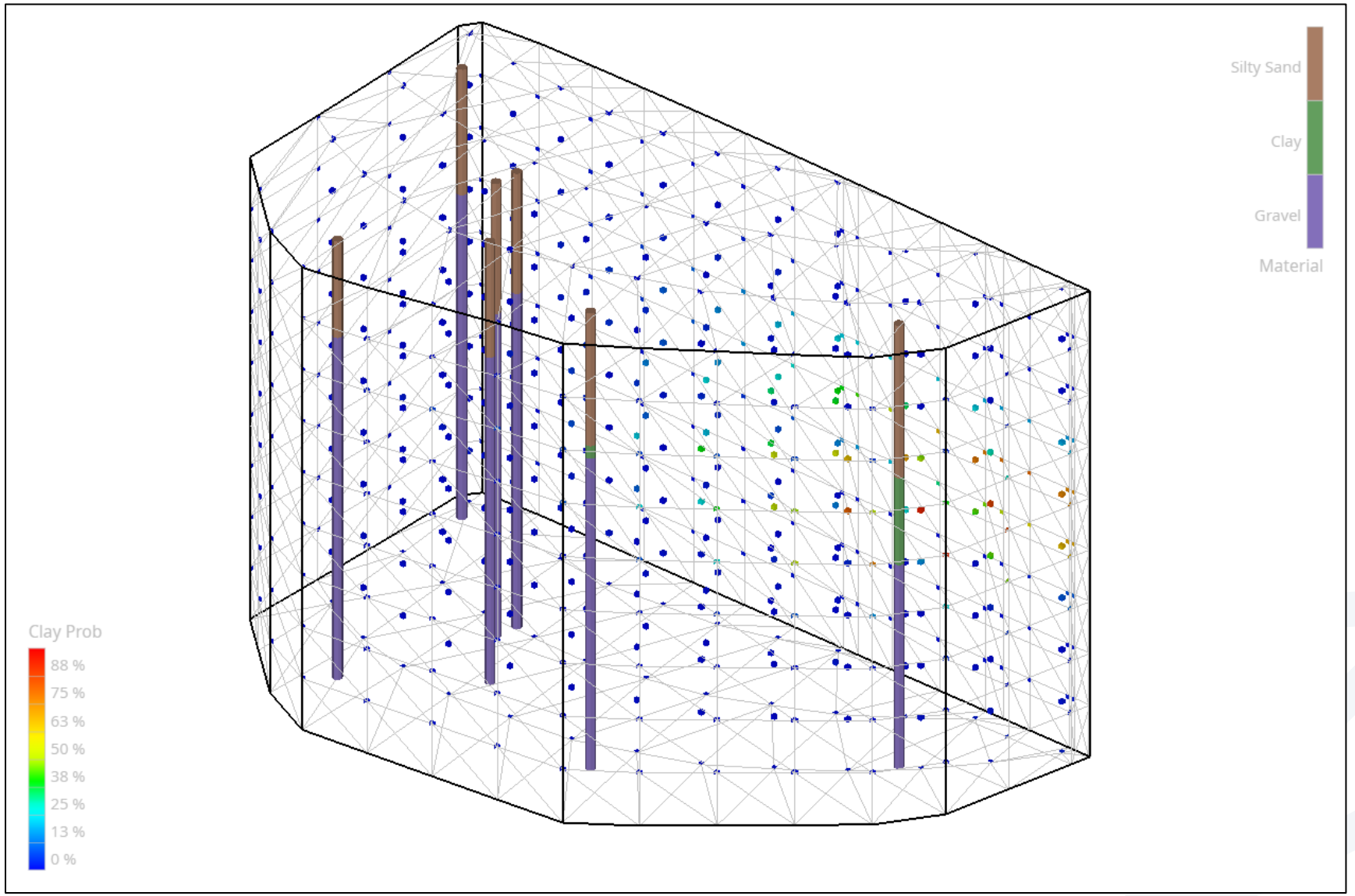
# EVS Approach – Indicator Kriging

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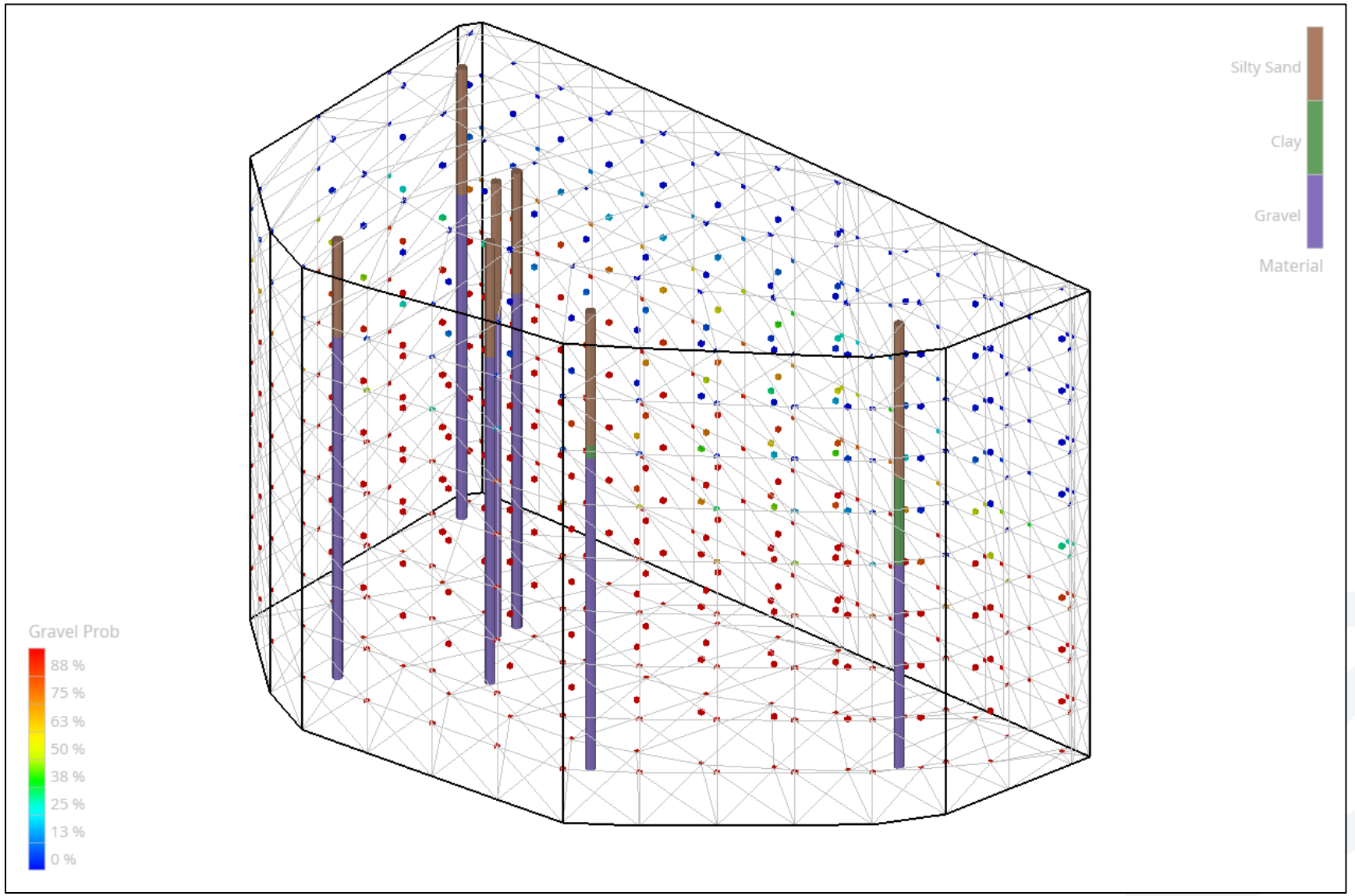
# EVS Approach – Indicator Kriging

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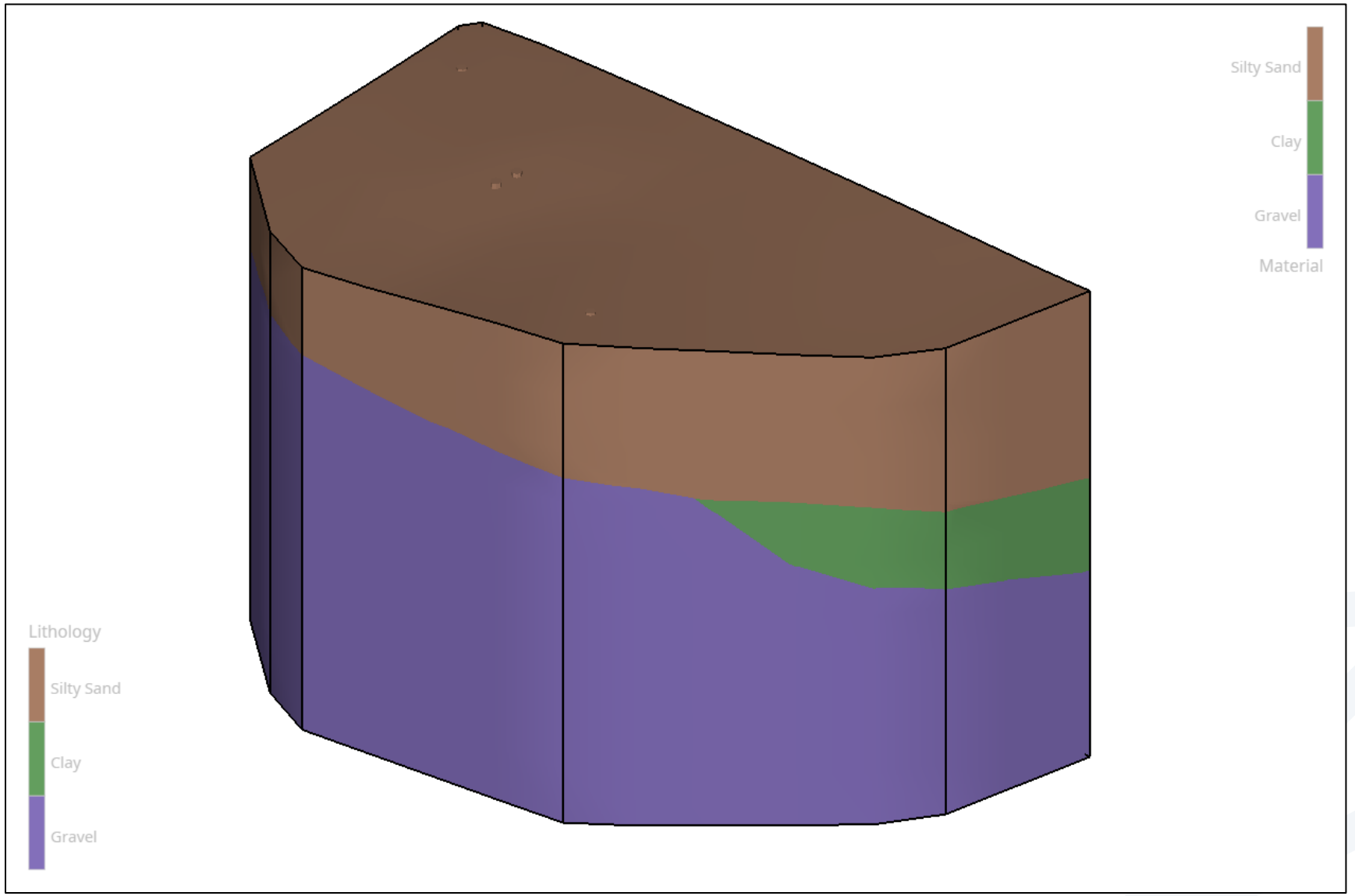
# EVS Approach – Indicator Kriging

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# EVS Approach – Temperature Kriging

- Assumption:
  - Surface water is cold
  - Warms as it travels through aquifer
  - Colder aquifer areas downgradient of reservoir = transport zones
- Selected April 2018 based on
  - Large dataset size
  - High temperature contrast
- Import temperature point measurements to EVS .APDV format
- Interpolate using 3D Estimation module
  - Estimates temperature at each grid node location

# EVS Model Result

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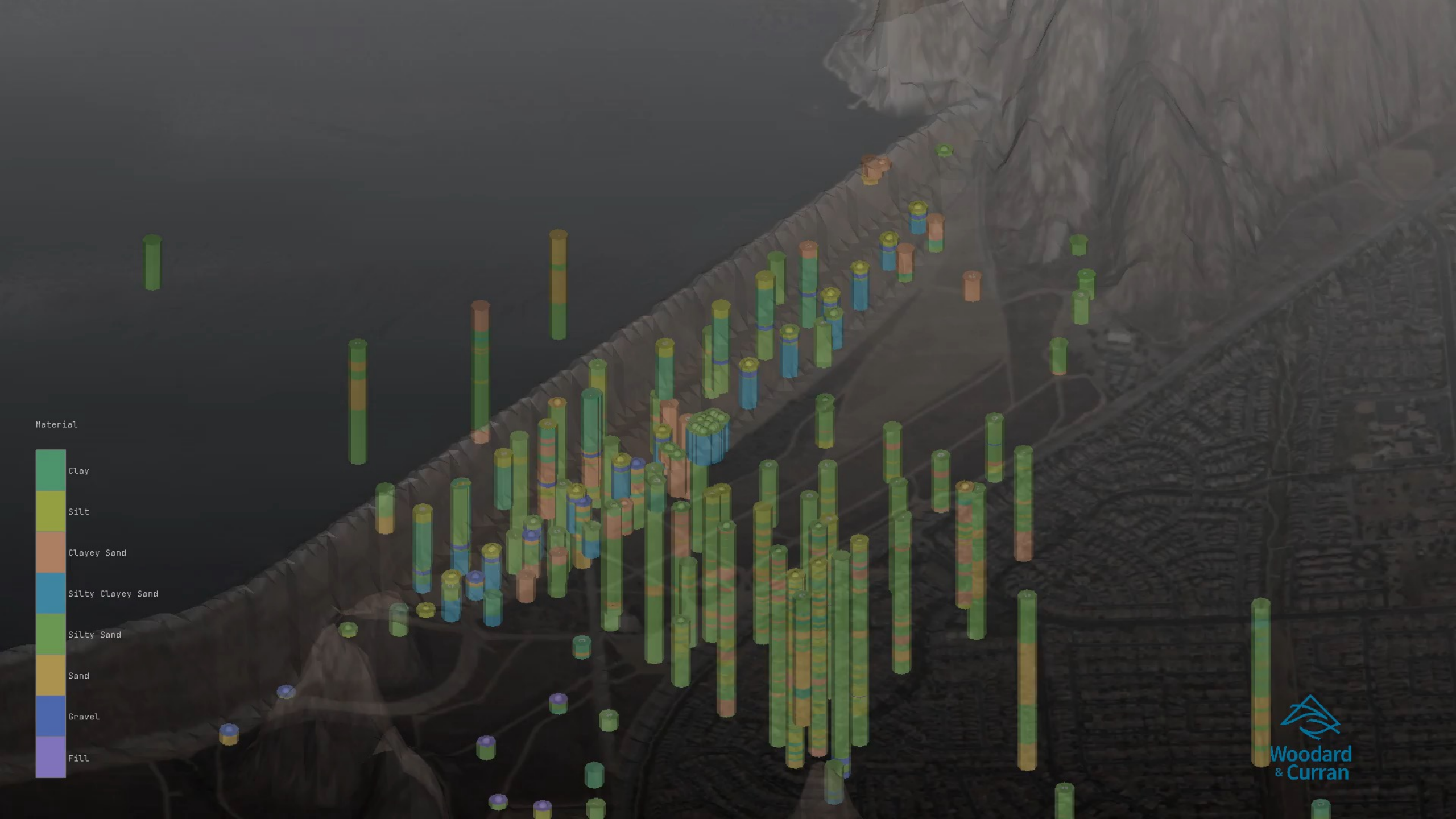
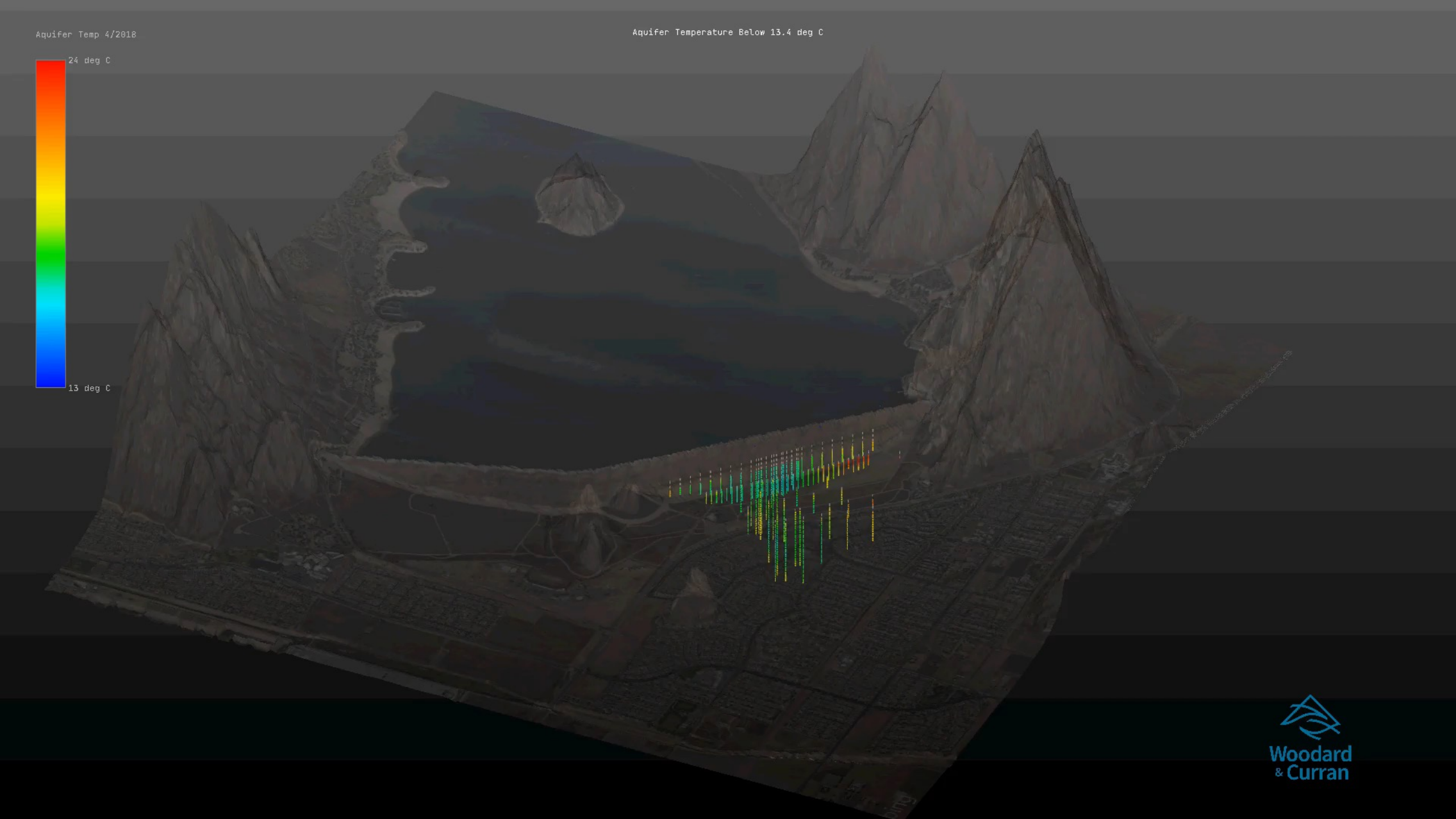

Material
Clay
Silt
Clayey Sand
Silty Clayey Sand
Silty Sand
Sand
Gravel
Fill
Woodard & Curran


Aquifer Temp 4/2018
24 deg C
13 deg C
Aquifer Temperature Below 13.4 deg C
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# Identification of MODFLOW calibration zones

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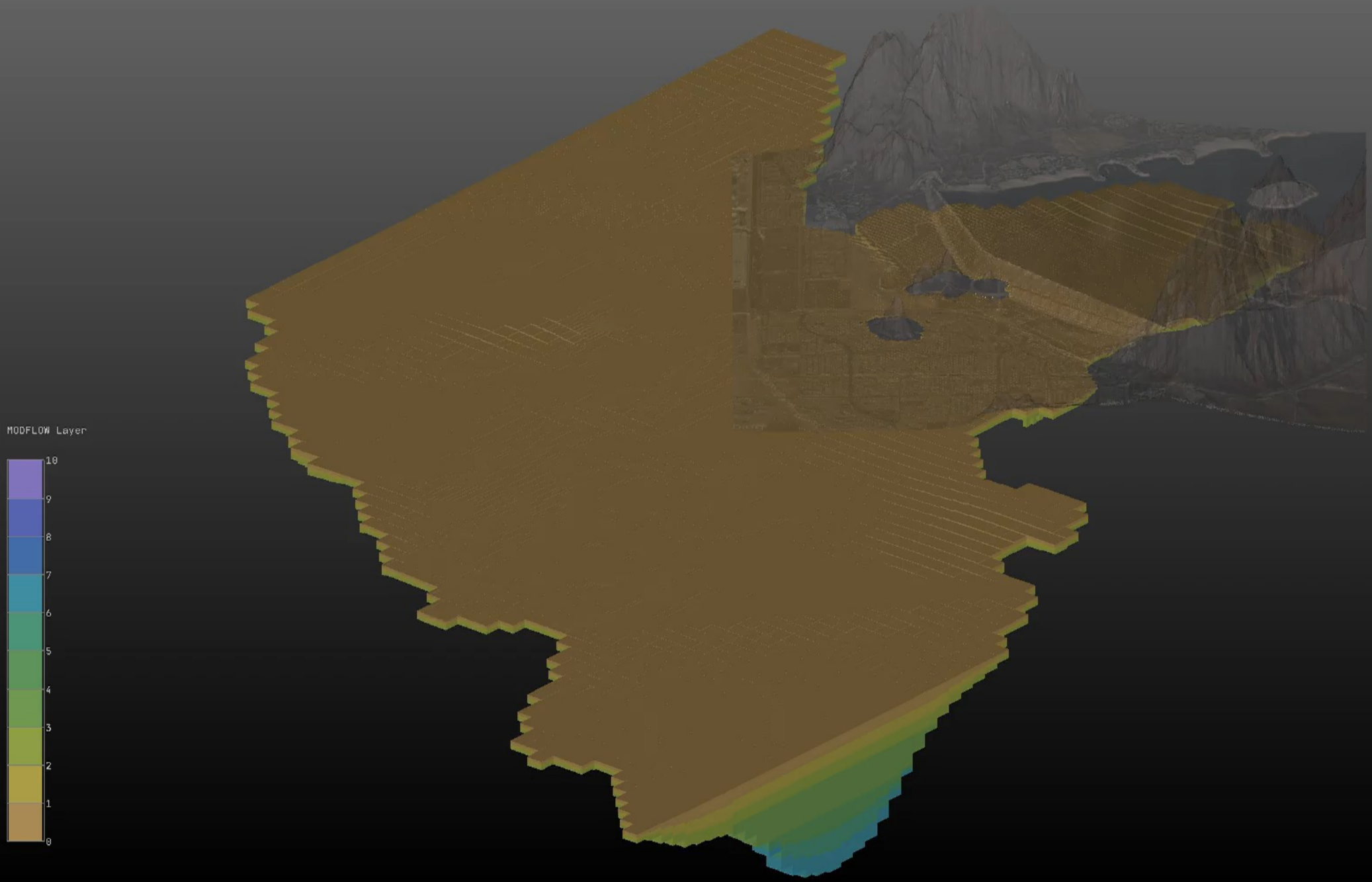
# EVS – Assign attributes to MODFLOW centroids

- Identify MODFLOW centroid points & import to EVS
- Use Interpolate Cell Data / Interpolate Node Data modules
  - Append lithology / temperature data from 3D models to MODFLOW centroids

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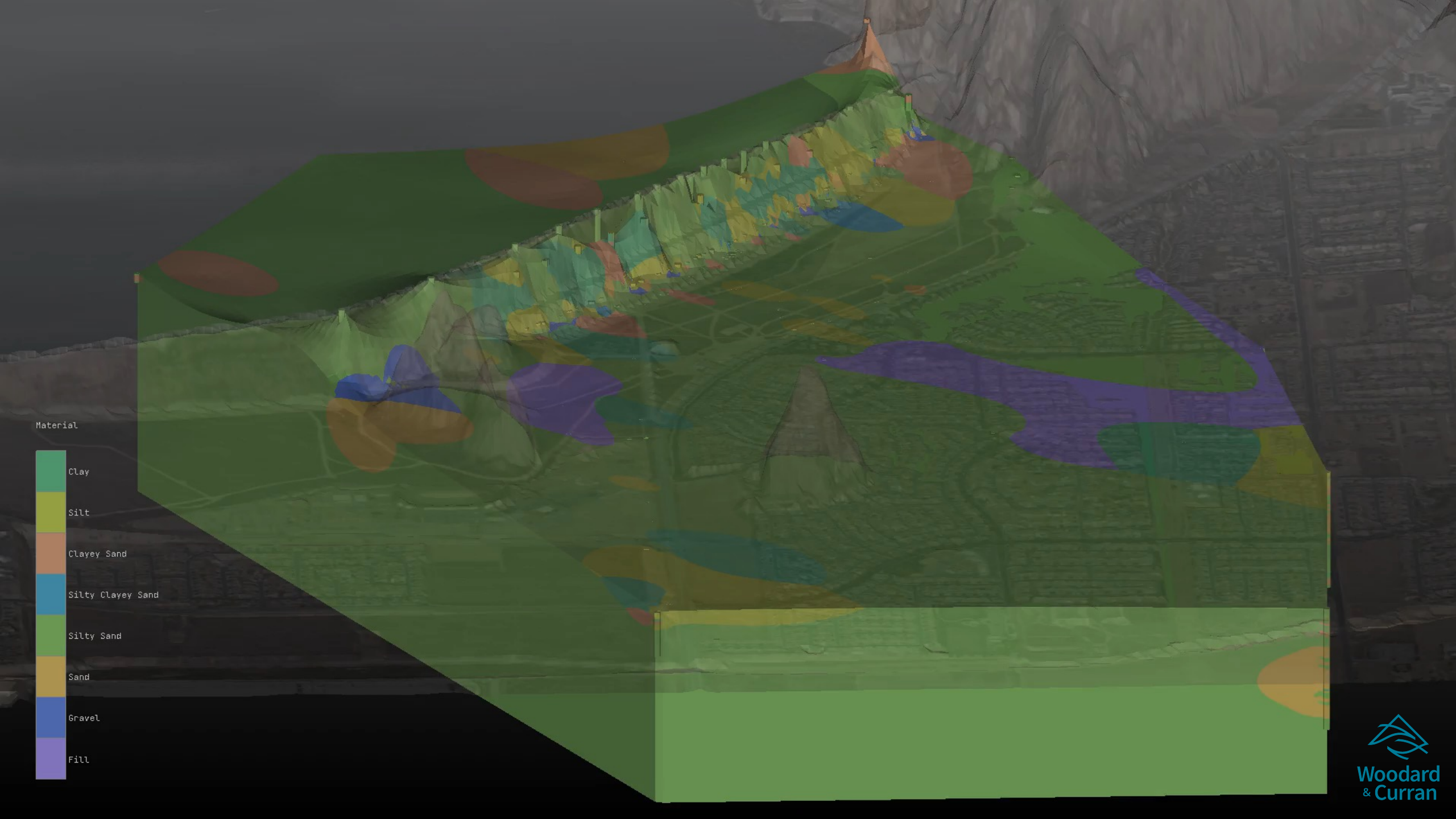
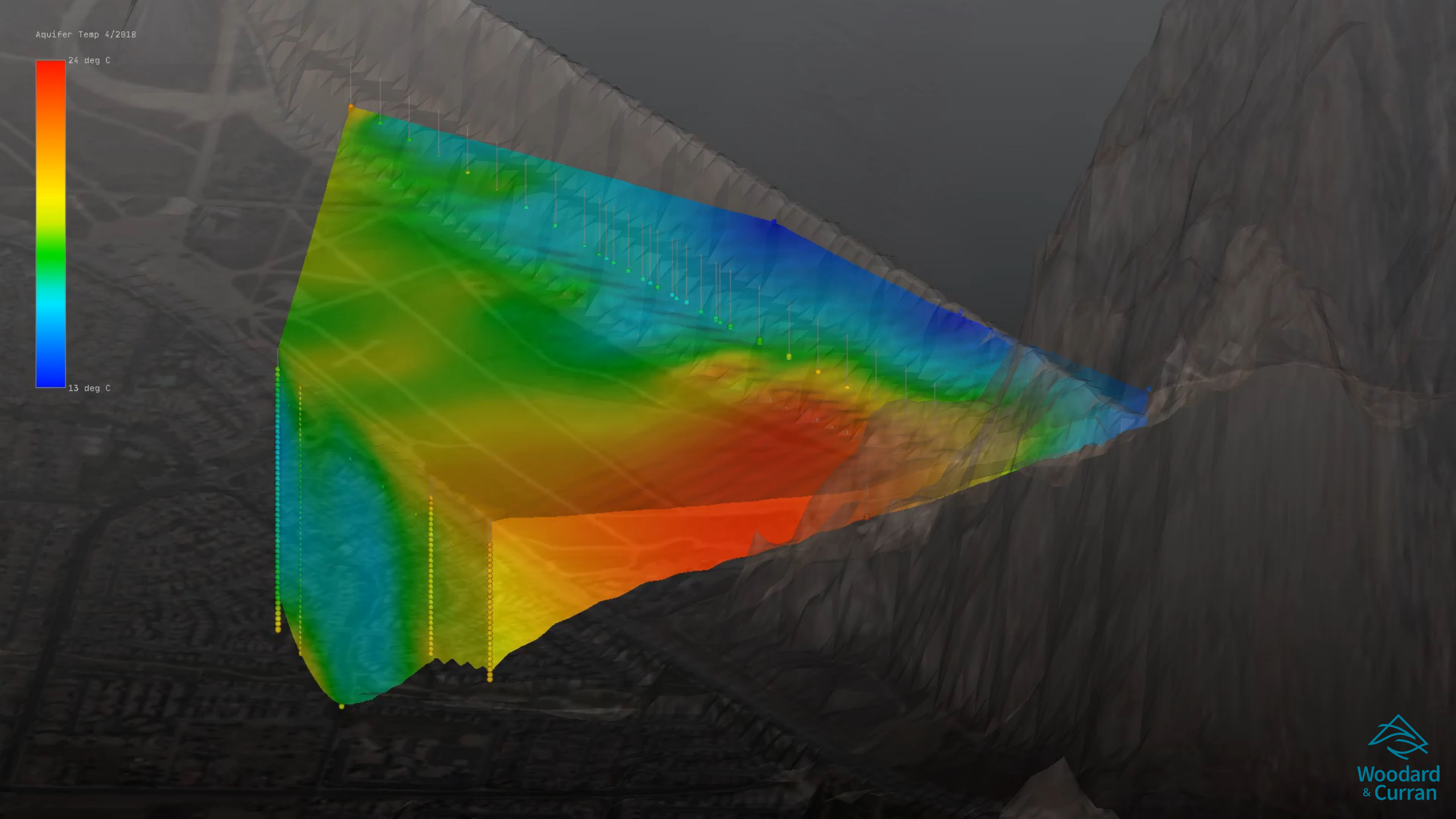
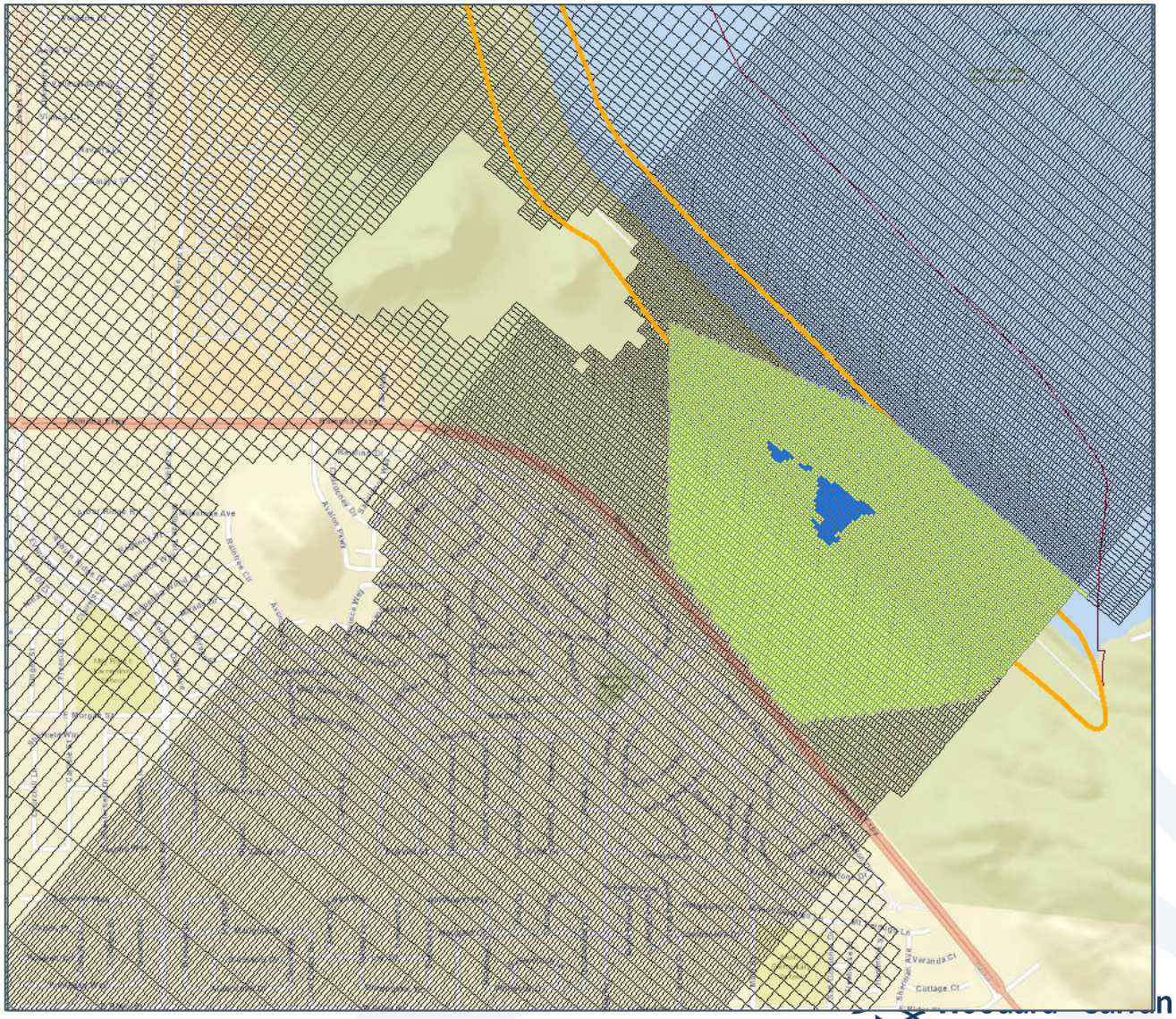

Material
Clay
Silt
Clayey Sand
Silty Clayey Sand
Silty Sand
Sand
Gravel
Fill
Woodard & Curran


Aquifer Temp 4/2018
24 deg C
13 deg C
Woodard & Curran

# EVS – Assign attributes to MODFLOW centroids

- Export cell centroid data
- Lithology Zones 1 - 8
- Manually categorize cells based on temperature for each MODFLOW layer
  - Append “A” to transmissive cells
  - “B” to less transmissive cells



# MODFLOW Zone Matrices for Each Layer

Output Matrix CrossTab_20210525

| 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | | | | | |
| 1 | 1 | 1 | 3 | 3A | 3B | | |
| 1 | 1 | 1 | 3 | 3A | 3A | 3B | 3B |
| 1 | 2 | 3 | 3A | 3A | 3A | 3B | 3B |
| 1 | 2 | 3A | 3A | 3A | 3A | 3B | 3B |
| 2 | 3 | 3A | 3A | 3A | 3A | 3B | 3B |
| 2 | 3A | 3A | 3A | 3A | 3A | 3B | 3B |
| 2 | 3A | 3A | 3A | 3A | 3A | 3B | 3B |
| 2A | 3A | 3A | 3A | 3A | 3A | 3A | 3B |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3A | 3A | 3A |
| 3A | 3A | 3A | 3A | 3A | 3B | 3B | 3B |
| 3A | 3A | 3A | 3A | 3B | 3B | 3B | 3B |

# MODFLOW was calibrated, run, & sensitivity analysis conducted

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# Results – EVS Display

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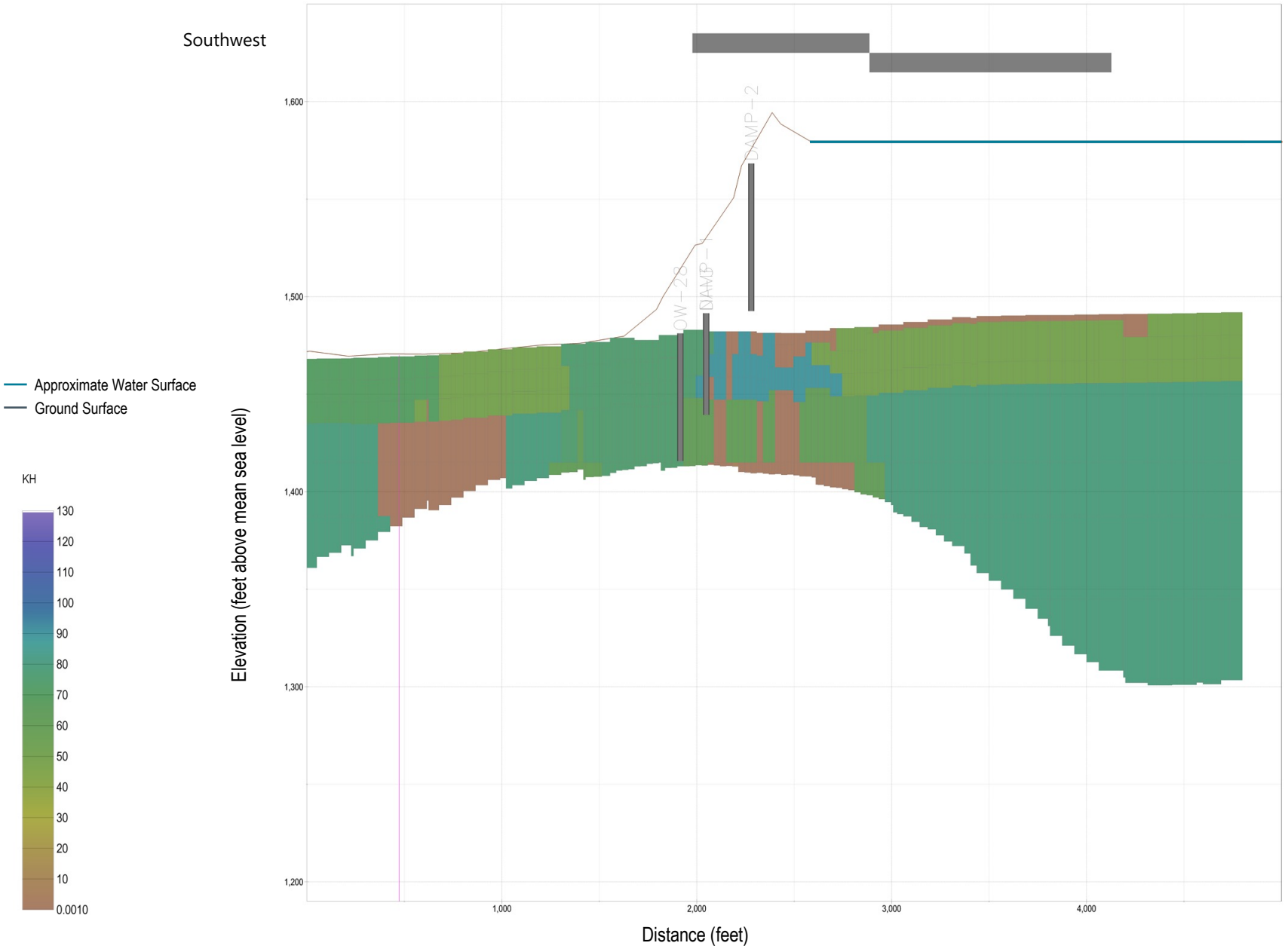
# MODFLOW Calibrated Horizontal K




Note:
*Vertical exaggeration = 10x

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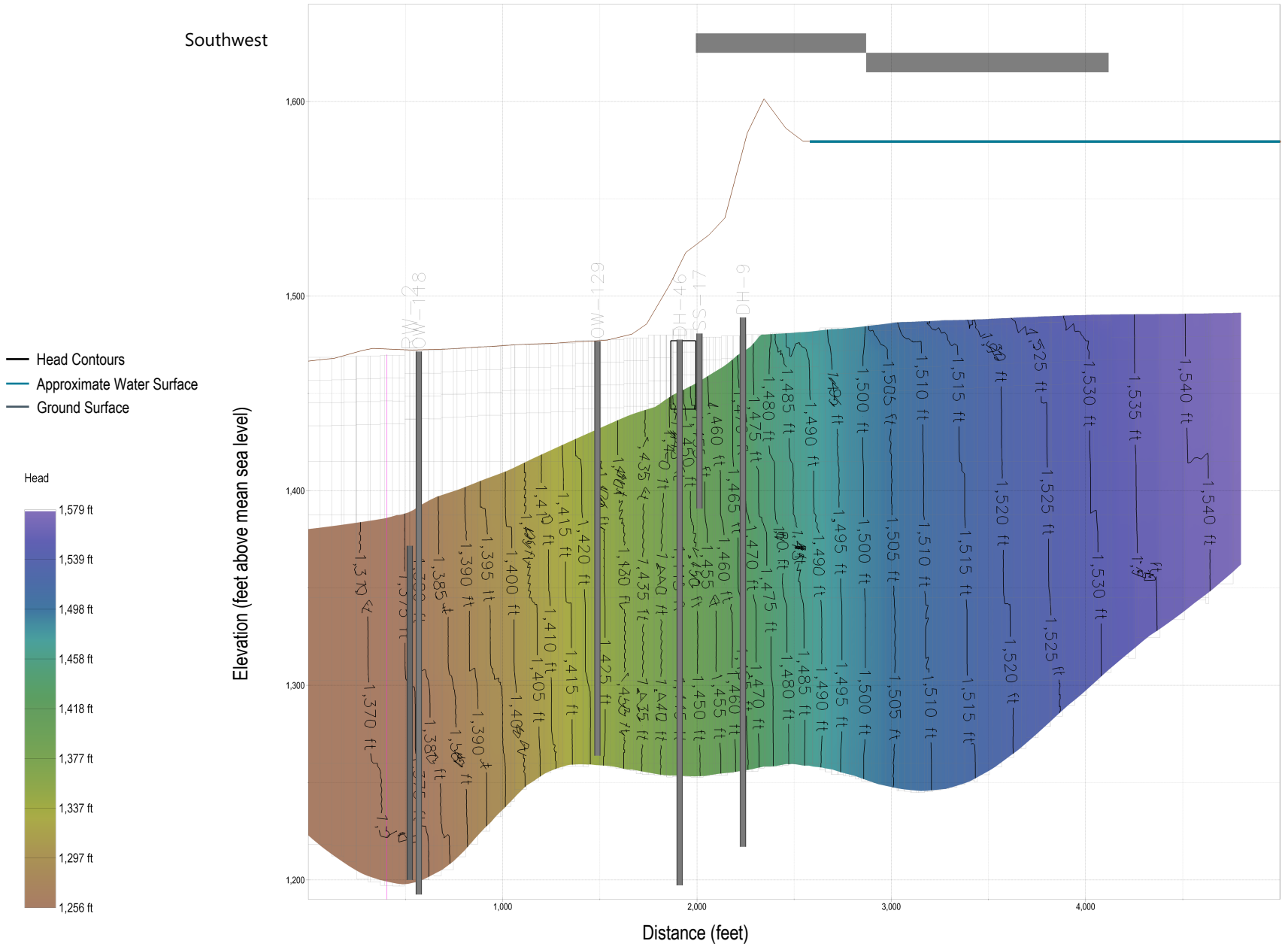
# MODFLOW Predicted Head




Note:
*Vertical exaggeration = 10x

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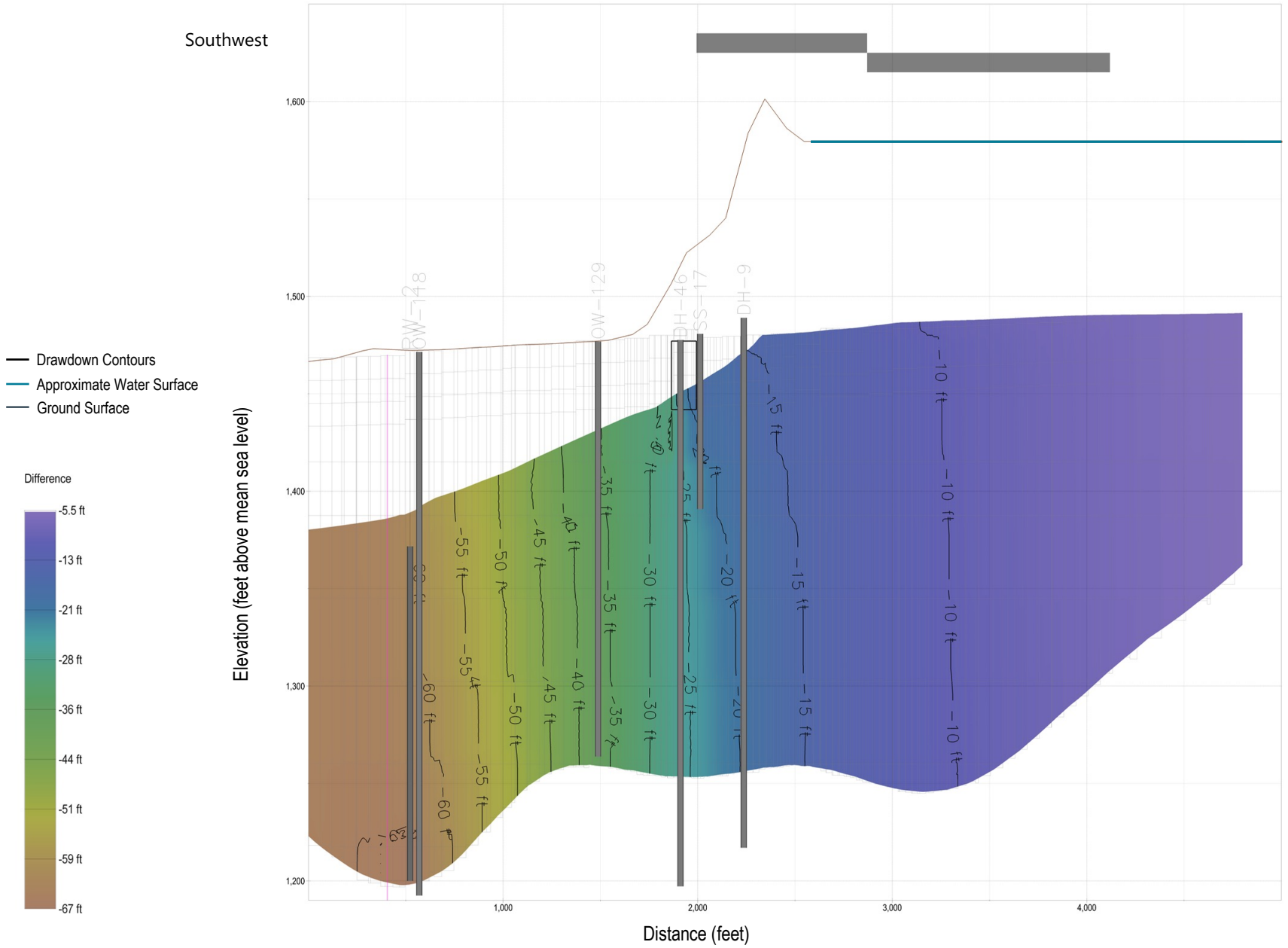
# MODFLOW Predicted Drawdown Under Pumping




Note:
*Vertical exaggeration = 10x

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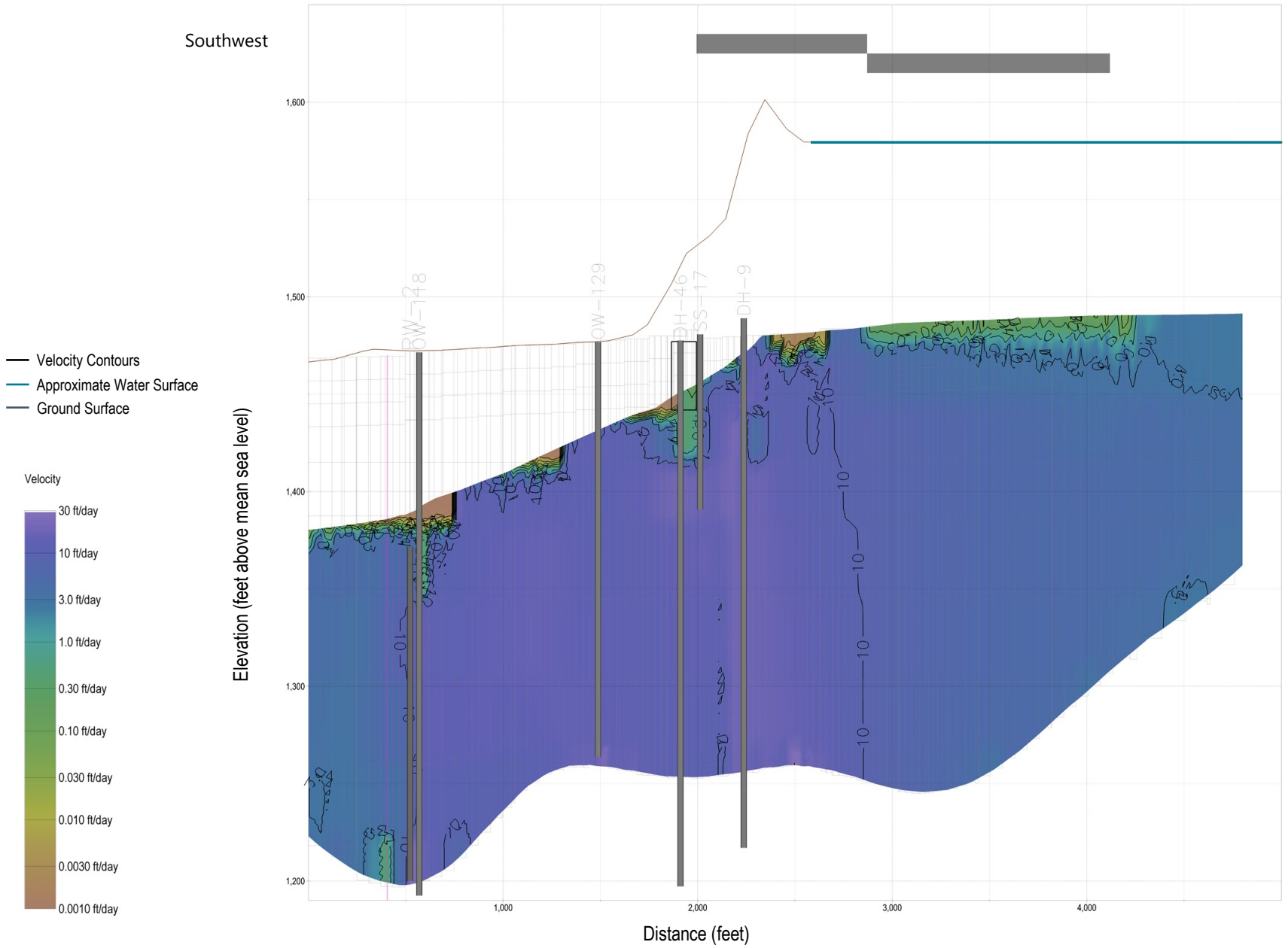
# MODFLOW Predicted Seepage Velocity




Note:
*Vertical exaggeration = 10x

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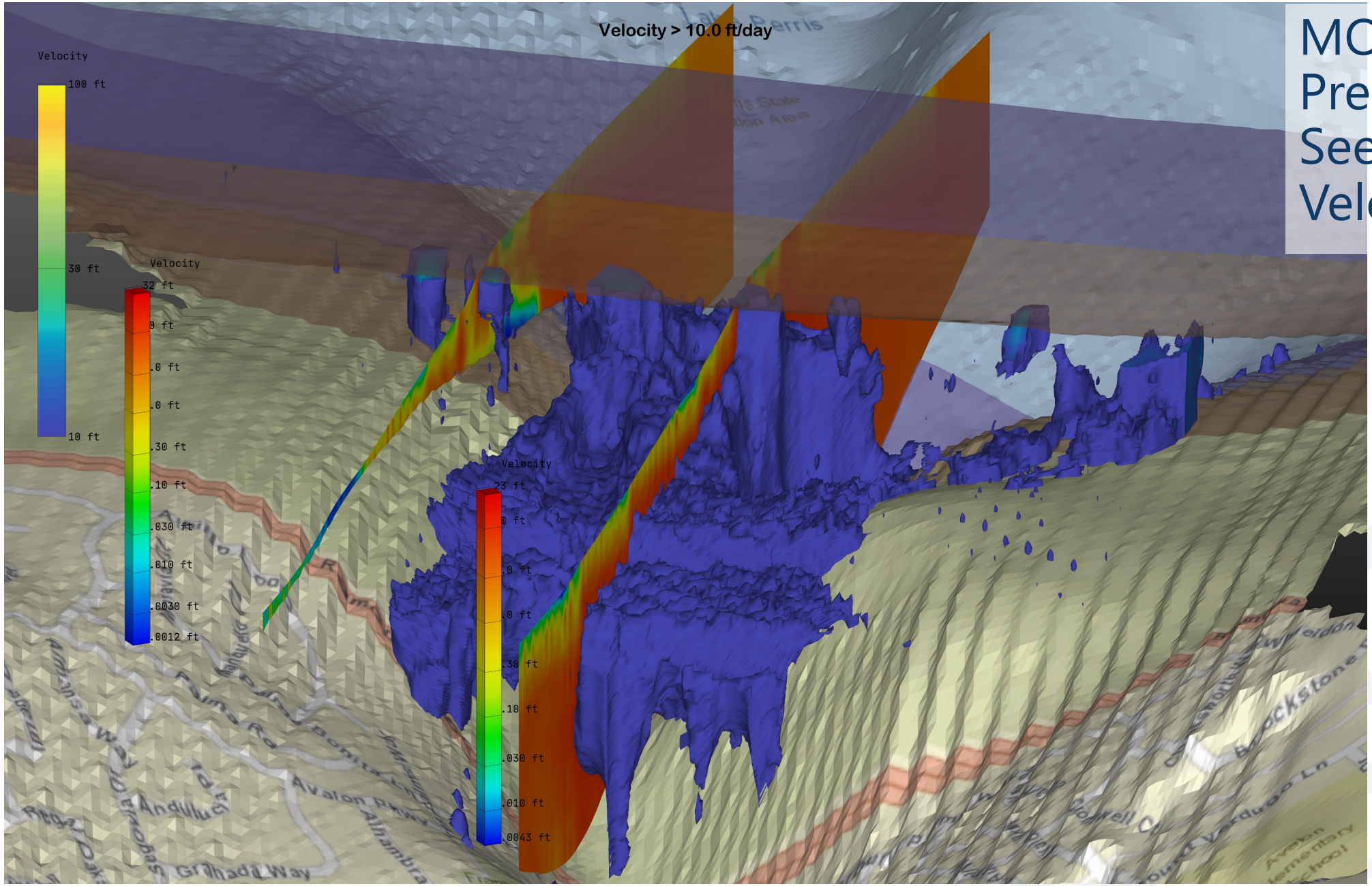
# MODFLOW Predicted Seepage Velocity 3D

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# Difficulties Encountered

- Cell lithology based on value at the cell centroid
  - May not account for large quantities of other materials in a cell
- Thermal data potential confounding factors
  - Vertical flow in aquifer or wells
  - Downgradient warming
  - Difficulty correlating temperature differential to aquifer properties
- Kriging lithology is resource intensive
- Scale of lithology & temperature models is large but must be high-resolution
- MODFLOW results require subsetting for use in EVS
- EVS data management limitations require other solutions

# Advantages of EVS Method

- MODFLOW model calibration zones and aquifer properties correspond with real site lithology
  - Further informed by temperature distribution
- Ability to evaluate MODFLOW results without respect to model grid
  - Oblique cross-sections, slices, maps, etc.
  - Augment results with other site features (wells, roads, trenches, etc.)
  - 3D, animation

# Thank You!

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