Appendix A

Contaminant of Concern Chemical Properties

TABLE A-1

CONSTITUENT OF CONCERN CHEMICAL PROPERTY DATA - UNSATURATED ZONE (0-15 FT BGS)

Former Chlorobenzene Process Area
Solutia Inc., W.G. Krummrich Facility, Sauget, Illinois

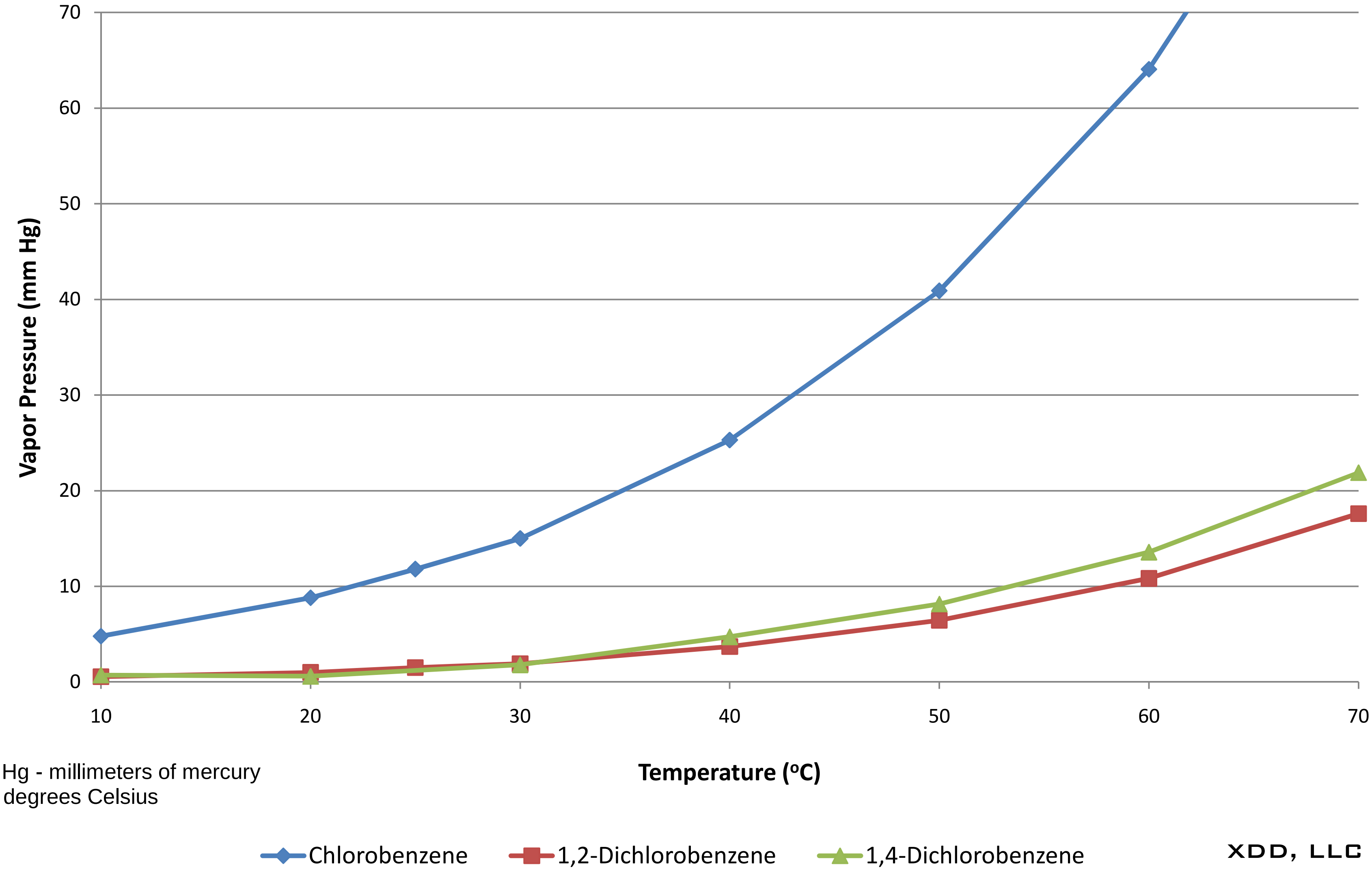
Constituent	CAS #	Solubility	Soil-Water Partition Coefficient	Soil Organic Carbon-Water Partition Coefficient	Henry's Law Constant	Diffusivity in Air	Diffusivity in Water	Apparent Diffusivity	Soil Saturation Limit
		(mg/L)	(Kd) (L/kg)	(Koc) (L/kg)	(dimensionless)	(cm^2/s)	(cm^2/s)	(cm^2/s)	(Csat) (mg/Kg)
Chlorobenzene	108-90-7	4.72E+02 (b)	1.31E+00 (a)	2.19E+02 (b)	1.52E-01 (b)	7.30E-02 (b)	8.70E-06 (b)	3.98E-04	3.07E+02
1,2-Dichlorobenzene	95-50-1	1.56E+02 (b)	3.70E+00 (a)	6.17E+02 (b)	7.79E-02 (b)	6.90E-02 (b)	7.90E-06 (b)	7.29E-05	2.25E+02
1,3-Dichlorobenzene	541-73-1	1.25E+02 (d)	2.59E+00 (a)	4.32E+02 (d)	1.08E-01 (d)	5.58E-02 (d)	8.85E-06 (d)	1.15E-04	1.80E+02
1,4-Dichlorobenzene	106-46-7	7.38E+01 (b)	3.70E+00 (a)	6.17E+02 (b)	9.96E-02 (b)	6.90E-02 (b)	7.90E-06 (b)	9.32E-05	---
Benzene	71-43-2	1.75E+03 (b)	3.53E-01 (a)	5.89E+01 (b)	2.28E-01 (b)	8.80E-02 (b)	9.80E-06 (b)	2.09E-03	5.91E+02
1,2,4-Trichlorobenzene	120-82-1	3.00E+02 (b)	1.07E+01 (a)	1.78E+03 (b)	5.82E-02 (b)	3.00E-02 (b)	8.23E-06 (b)	8.38E-06	1.13E+03

foc - fraction organic carbon.
L - liters
mg - milligrams
Kg - Kilograms
cm - centimeters
--- - not calculated

(a) - Kd = Koc*foc, where foc = 0.006, per (b)
(b) - USEPA, 2002. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Exhibit C-1.
(c) - Equation 4-8 from USEPA, 2002. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.
(d) - Risk Assessment Information System. http://rais.ornl.gov/tox/tox_values.shtml

Note:
1. Table Source: URS Corporation, Former Chlorobenzene Process Area Characterization Report, February 2010.

FIGURE A-1
CHANGES IN VAPOR PRESSURE DUE TO INCREASED TEMPERATURE - FOR SELECT CONTAMINANTS
Former Chlorobenzene Process Area
W.G. Krummrich Facility, Sauget, Illinois



mm Hg - millimeters of mercury
°C - degrees Celsius

XDD, LLC

Appendix B

Heat Modeling Simulations

1.0 SUMMARY OF HEAT MODELING

The target subsurface soil temperature for the Thermally Enhanced Soil Vapor Extraction (T-SVE) treatment is between 40 to 60 degrees Celsius (^oC). This temperature range is designed to increase the volatility of the target compounds to enhance extraction. The proposed heating mechanism is to inject a steam-air mixture using the Air Injection (AI) wells.

1.1 SOIL HEATING/STEAM DESIGN MODELING

A computer model simulation was performed to evaluate the heating performance of various volumes of steam for an initial soil heating phase.

- Initial Heating Phase: The soils are assumed to be at approximately 10^{o}C initially, so a soil temperature rise of 30 to 50^{o}C will be required. The specific-heat capacity of soils (i.e., heat required to raise the temperature by one degree) requires that a larger volume of steam will initially be required to supply enough heat energy to reach the desired temperature in a reasonable time period. Heat-losses will also be occurring from heat transfer to atmosphere, to the intermittent silty clay layer, and to the underlying groundwater flow below the target intervals. These potential heat sinks were included in the design estimates. An insulating concrete surface cap is included in the design to reduce heat loss to the atmosphere.

- Temperature Maintenance Phase: When the subsurface reaches the desired temperature, the AI/Steam system may be readjusted to use less of steam to maintain subsurface temperatures. The maintenance heat requirement will be based upon providing enough heat energy to balance the potential heat-losses (i.e., heat loss across the thermal cap to atmosphere, to the underlying groundwater, etc.). This reduces steam usage and overall energy requirements as well as potential condensation in the subsurface.

1.2 COMPUTER MODEL GRID DESIGN

The computer modeling was performed by Dr. Brent Sleep (University of Toronto). The model grid was designed as an 80 feet x 80 feet area (24 meters [m] x 24 m) to simulate the 40-foot center to center well spacing design for the full-scale T-SVE system. The overall model grid thickness was set at 20 feet deep (~6 m).

The model was divided into five primary layers, including:

- Layer 0/Surface Cap: The surface cap layer was assumed to be either an 8 inch standard concrete cap or a 12 inch thick Elastizell® lightweight/aerated concrete cover:
  - Concrete: Thermal conductivity of 0.4 to 0.7 Watts/meter Kelvin (W/m K).
  - Elastizell® Aerated Concrete: Thermal conductivity of 0.1 W/m K, which is equivalent to an R-Value of 18 (R=1.5/inch according to manufacturer specifications).
- Layer 1: Shallow zone (fill/upper silty sand) from 0-5 feet below ground surface (feet bgs). This layer remained unsaturated for all model simulations.
- Layer 2: Intermediate silty clay zone from 5-10 feet bgs. This layer remained unsaturated for all model simulations.
- Layer 3: Deep zone (lower silty sand) from 10-15 feet bgs. This layer was either saturated or unsaturated, depending on the assumed water table elevation for each simulation.
- Layer 4/Saturated Zone: The water table elevation was varied between 10 and 15 feet bgs. As such, the Deep zone (Layer 3) was submerged during some of simulations. This was performed to simulate the potential determine if shallow groundwater conditions

would present a significant increase in heat loss for the Shallow zone (Layer 1) simulations. Therefore, between 5 and 10 feet of water thickness would be included in the model domain depending on the simulation parameters (i.e., total model thickness of 20 feet).

Model SVE/AI Wells: A dual level AI/Steam injection well (shallow and deep screen in Layer 1 and Layer 3, respectively) was located in the center of the model grid. Dual level SVE extraction wells (shallow and deep screens in Layer 1 and Layer 3, respectively) were located at four edges of the model grid. SVE wells are located 40 feet (center to center) from the AI/Steam injection well.

The shallow well screens were assumed to be at a depth of 1 to 5 feet bgs. The deep well screens were assumed to be at a depth of 10 to 14 feet bgs.

Air Injection/Extraction Rates: The AI/Steam injection wells were assumed to be injecting air/steam at 50 standard cubic feet per minute (scfm). The SVE wells were assumed to be extracting at a total of 50 scfm. Simulations were performed assuming that air injection/heating and extraction was occurring within a single layer at a given time (i.e., Layer 1 or Layer 3 separately).

Soil Permeability: Air permeability (*k*) for the Shallow and Deep layers (Layers 1 and 3) was assumed to be 1.2×10^{-7} centimeters squared (cm^2). This was based on the conversion of the reported CPA hydraulic conductivity (*K*) of 0.01 centimeters/second (cm/sec) to an intrinsic air permeability. This value is consistent with the SVE pilot testing in the Big Mo area (2009-2010), which yielded an estimated air permeability for the sandy fill/upper silty sand unit of 3.94×10^{-7} cm^2. The computer model predicted a well head injection pressure of approximately

59 inches of water (in. H_2O), which is also in close agreement with the observed well head injection pressure during the Big Mo area pilot testing.

1.3 SIMULATION RESULTS

The air-to-steam ratios that are estimated to be required for the initial heating phase of operation are presented in **Table B-1**. Actual steam injection ratios may be optimized based upon actual subsurface heating performance and temperature monitoring via vapor probes. The graphical heat distribution (and water saturation results of selected scenarios) from the soil heating simulations are attached.

Six simulations (**Simulations 01 through 06**) were performed. The following parameters were varied during the simulations:

1. Initial process air temperature prior to steam addition (i.e., ranging from standard conditions of 20^{o}C to 100^{o}C).
2. Steam injection mixture ratio (ranging from 10% to 20% by volume of the 50 scfm injection flow).
3. Surface cap thermal insulation value:
    a. Standard concrete.
    b. Thermal concrete (Elastizell®) enhanced insulation value (R=18).
    c. Infinite insulation value (i.e., zero heat loss through the cap).
4. Depth of water table (10 or 15 feet bgs), and assumed groundwater velocity of 10.4 feet/year.
5. Target heating depth interval (shallow zone or deep zone).

Other constants/assumptions used in the simulations include:

1. Ambient atmospheric temperature was set at 20°C (68 degrees Fahrenheit [°F]). Heat loss may be lower or higher when ambient temperatures change seasonally.
2. The heat conducts to the water table, the intermediate silty clay layer, and through the surface cap to atmosphere were included (with the exception that no heat loss to atmosphere was allowed for the scenario which assumed the infinite insulation value for the surface cap).
3. Air injection rate was assumed to be 50 scfm in all simulations.
4. SVE extraction rate was assumed to be 50 scfm total in all simulations.

1.3.1 SIMULATION 1 – SHALLOW ZONE, 20% STEAM AT 60°C, CONCRETE CAP

This scenario assumed that the inlet air temperature, prior to steam addition, was 20°C. Steam was mixed with the inlet air at a 20% steam/80% air molar volume ratio. The resulting air-steam mixture temperature was approximately 60°C (saturated steam conditions). A standard 8 inch thick concrete cap was assumed for reducing heat loss to atmosphere (heat absorption by the concrete itself was not included).

Results are shown in the **Simulation 01A** figure. At 200 days the heated zone around the injection well has only reached a 12 foot radius. At this time, the heat loss through the surface is balancing out heat energy addition, so expansion of heated zone become minimal after 200 days.

Based on this simulation, the effect of heat loss through the surface cap was evaluated in the next simulation (**Simulation 02**).

1.3.2 SIMULATION 2 – SHALLOW ZONE, 20% STEAM AT 60^{o}C, NO HEAT LOSS TO ATM.

For this simulation, it was assumed that there was no heat loss across the cap to atmosphere (perfect insulating value), and there was also no heat absorption by the cap. This scenario assumed that the inlet air temperature, prior to steam addition, was 20^{o}C (same as **Simulation 01**). Steam was mixed with the inlet air at a 20% steam/80% air molar volume ratio. The resulting air-steam mixture temperature was approximately 60^{o}C (saturated steam conditions).

Results are shown in the **Simulations 02A through 02C** figures. At 100 days the heated zone around the injection well has expanded to the extraction wells. By eliminating heat loss to atmosphere, a lower temperature injection mixture can adequately heat the target interval in a reasonable time.

A "zero-heat loss" to atmosphere assumption is not realistic; however, this simulation suggests that maximizing the surface cap insulation value will help to optimize the heating performance. Therefore, based on this simulation, a higher insulation value cap (e.g., Elastizell®) was added to the next simulation (**Simulation 03**).

1.3.3 SIMULATION 3 – SHALLOW ZONE, 20% STEAM AT 60^{o}C, ELASTIZELL CAP

This scenario includes a higher value insulation cap (12 inch thick Elastizell® aerated concrete). This scenario also assumed that the inlet air temperature, prior to steam addition, was 20^{o}C, and steam was mixed with the inlet air at a 20% steam/80% air molar volume ratio (same as the prior **Simulations 01 and 02**). The resulting air-steam mixture temperature was approximately 60^{o}C (saturated steam conditions). For this simulation, there was also no heat absorption by the cap itself. The water table elevation was 15 feet bgs in this simulation.

Results are shown in the **Simulations 03A through 03E** figures. At slightly over 100 days, the heated zone around the injection well has expanded to the extraction wells. The addition of the higher insulating value surface cap increases the efficiency of the soil heating process.

Based on this simulation, a higher insulation value cap (e.g., Elastizell®) will be required to heat the soils in a reasonable time frame, while still using relatively low steam mixture ratio. Therefore, the remaining simulations were performed assuming that a 12 inch thick Elastizell® cap (or similar) would be installed.

The next simulations were performed to evaluate the effect of using an overall higher injection temperature (100°C) (see **Simulation 04** below), but lower steam mix ratios.

1.3.4 Simulation 4 – Shallow Zone, 10% Steam at 100°C, Elastizell Cap

This scenario assumes that the inlet air temperature, prior to steam addition, is at least 50°C (this is the anticipated air temperature that will be present in the process stream due to the operation of the AI air compressor/blowers). It was then assumed that steam would be added to raise the overall mix temperature to 100°C and the final resulting mix ratio in the injection air would be at a 10% steam/90% air molar volume. This is an under-saturated steam mixture at this temperature.

Note that to create this final injection mixture, a slightly higher steam ratio (i.e., > 10%) would actually be required to first heat the inlet air from 50°C to 100°C, and some of the steam would condense during this operation. For the purposes of this simulation however, it was assumed that the actual air being injected into the subsurface would contain 10% steam, and would be at 100°C.

The higher value insulation cap (12 inch thick Elastizell® aerated concrete) was assumed, and there was no heat absorption by the cap itself. The water table elevation was reduced to 10 feet bgs in this simulation.

Results are shown in the **Simulations 04A and 04B** figures. Even though the air temperature is hotter than prior simulations, the target interval is only just attaining the desired heat distribution within 200 days. This is because the steam content is lower in this simulation, so the heating is slower than the prior simulations (compare the **Simulation 04A** figure to the **Simulation 03D.ii** figure, which shows much improved heat distribution for 20% steam at 60^{o}C at 100 days). The primary reason for this is that most of the heat energy associated with the air injection mixture is related to the water content, so the lower steam content reduces heat transfer. Also, note that the water table elevation was also higher in **Simulation 04A** (10 feet bgs) as compared to **Simulation 03D.ii** (15 feet bgs), but this has only a minimal effect on the heating performance.

Another factor affecting the performance is that since this 10% injection mixture is under-saturated with steam at 100^{o}C, there is some pore water evaporation in the subsurface, which results in some evaporative cooling while drying out the soils. In the **Simulation 04B** figure, the change in water saturations are shown, and a zone of dryer soils is observed (in particular, closer to the injection well).

The next simulation was performed to evaluate the effect of increase the steam content, while maintaining the high injection temperature of 100^{o}C (see **Simulation 05** below).

1.3.5 SIMULATION 5 – SHALLOW ZONE, 20% STEAM AT 100^{O}C, ELASTIZELL CAP

This scenario assumed that saturated steam would be added to the process air to raise the overall mix temperature to 100^{o}C, and the final resulting mix ratio in the injection air would be at a 20%

steam/80% air molar volume. This is also an under-saturated steam mixture at this temperature, similar to the prior simulation.

The higher value insulation cap (12 inch thick Elastizell® aerated concrete) was assumed, and there was no heat absorption by the cap itself. The water table elevation was assumed to be 10 feet bgs in this simulation.

Results are shown in the **Simulations 05A and 05B** figures. The increased steam content in this mixture improves the heating performance as compared to prior simulations:

- The performance is slightly improved compared to the **Simulation 03D.ii** figure, which assumed a 20% steam mixture at 60^{o}C (note that the water table was deeper at 15 feet bgs for this simulation).
- The heating performance was significantly improved over the 10% steam/100^{o}C mixture scenario (refer to **Simulation 04A** figure, for 10% steam at 100^{o}C at 100 days).

This simulation represents the most likely minimum steam content/injection temperature required to achieve the desired heat distribution within a reasonable timeframe.

1.3.6 Simulation 6 – Deep Zone, 20% Steam at 100^{O}C, Elastizell Cap

This scenario was performed for the deep zone interval (10-15 feet bgs). The water table elevation was assumed to be 15 feet bgs in this simulation.

This scenario used the minimum required steam content/air temperature mixture that was determined for the shallow zone (20% steam/80% air molar volume at 100^{o}C). This is an under-saturated steam mixture at this temperature, so some pore water evaporation is expected (though less than in the 10% steam/90% air simulation). The higher value insulation cap (12 inch thick Elastizell® aerated concrete) was assumed, and there was no heat absorption by the cap itself.

The results are presented in the **Simulation 6A** figure. This figure shows that there is some heat loss through the overlying intermediate silty clay layer, and to the underlying groundwater table. However, the target interval is heated within 200 days. Additional steam content (i.e., > 20%) will likely be needed within the deep target interval to reduce the heating time.

1.4 SUMMARY OF MODELING RESULTS

These heat modeling simulations were designed to provide the minimum steam injection ratios and surface insulation requirements. At a minimum, the following design parameters will be used for the full-scale design:

1. Surface Insulation: A surface insulation cap of a minimum R value of 18 will be used (e.g., such as an Elastizell® aerated concrete cap, 12 inches thick, or equivalent). The heat loss to atmosphere had a significant effect on the overall soil heating performance.

2. Minimum Steam Injection Ratio: A minimum steam injection ratio of 20% by volume (80% air) at 100^{o}C will likely be required to achieve the required heat distribution in the shallow zone within a reasonable time frame, during the initial heating phase. Steam injection ratios of slightly greater than 20% will be required for the deep zone. The system will be designed to handle higher steam addition ratios, so that the heat addition can be optimized based upon actual temperature distribution (as indicated by temperature measurements in available vapor probes).

3. Flow Optimization: Note that higher injection flowrates than 50 scfm at individual AI/Steam wells can be achieved under actual field operating conditions. The 50 scfm injection rates is the "average" injection rate per well, based on the overall AI blower/compressor capacity and the maximum number of wells that can be operated at a given time. As the system is optimized, higher injection flowrates can be applied to the most impacted areas, to introduce more heat more quickly and increase the temperature, as needed.

4. Temperature Maintenance: As the soils achieve the target temperature distribution after the initial heating phase, the steam injection rate can possibly be reduced to where the heat input balances the heat losses to various heat sinks in the system (i.e., heat loss to atmosphere through the cap, absorption to the intermediate silty clay layer, and heat loss to the groundwater).

TABLE B-1

Steam Injection/Heat Modeling Simulation Results

Chlorobenzene Process Area (CPA) Thermally Enhanced Soil Vapor Extraction (T-SVE) Treatment

Solutia Inc. W.G. Krummrich Plant, Sauget, Illinois

Scenario	Inlet Air						Steam Addition		Surface Cap Insulation Value	Water Table Elevation	Results
	Air Temp. (t)		Relative Humidity (prior to steam addition)	Max. Saturated Water Vapor Pressure at Air Temp. (t)[1]		Max. Water Content at Air Temp. (t)	Steam Mix Ratio				
Soil Heating Phase - Shallow	°C	°F	%	kPa	psia	kg/kg	Vol/Vol	kg/kg		feet bgs	
Simulation 1 - 20% Steam at 60C/Concrete	60	140	4.23%	19.92	2.89	0.152	20%	0.155	Concrete	15	Heating distribution not achieved (12 foot radius max)
Simulation 2 - 20% Steam at 60C/No Heat Loss	60	140	4.23%	19.92	2.89	0.152	20%	0.155	No Heat Loss (perfect insulation)	15	Heating distribution achieved in less than 100 days
Simulation 3 - 20% Steam at 60C/Elastizell	60	140	4.23%	19.92	2.89	0.152	20%	0.155	Elastizell (R=18)	15	Heating distribution achieved in approx. 100 days
Simulation 4 - 10% Steam at 100C/Elastizell	100	212	0.83%	101.33	14.70	100% sat. steam	10%	0.069	Elastizell (R=18)	10	Heating distribution achieved, but requires over 200 days
Simulation 5 - 20% Steam at 100C/Elastizell	100	212	0.83%	101.33	14.70	100% sat. steam	20%	0.155	Elastizell (R=18)	10	Heating distribution achieved in approx. 100 days
Soil Heating Phase - Deep	°C	°F	%	kPa	psia	kg/kg	Vol/Vol	kg/kg	Insulation Value	feet bgs	Results
Simulation 6 - 20% Steam at 100C/Elastizell	100	212	0.83%	101.33	14.70	100% sat. steam	20%	0.155	Elastizell (R=18)	15	Heating distribution achieved in approx. 200 days, requires higher steam addition to reduce heating time

Notes:

AI = Air Injection
°C = Degrees Celsius
°F = Degress Fahrenheit
RH = Relative Humidity
in. H_2O = inches of water pressure

SVE = Soil Vapor Extraction
psia = pounds per square inch absolute pressure
psig = pounds per square inch gauge pressure
Lbs = pounds
kPa = kilopascals

acfm = actual cubic feet pre minute (at actual conditions)
scfm = standard cubic feet per minute (at Standard Conditions)
kj = kilojoules
Temp. Conversion Eq.: Tc = (5/9)*(Tf-32); Tf = (9/5)*(Tc)+32
Tc = Temp. °C; Tf = Temp. °F

m^3 = cubic meters
R = R-Value for insulation
feet bgs = feet below ground surface

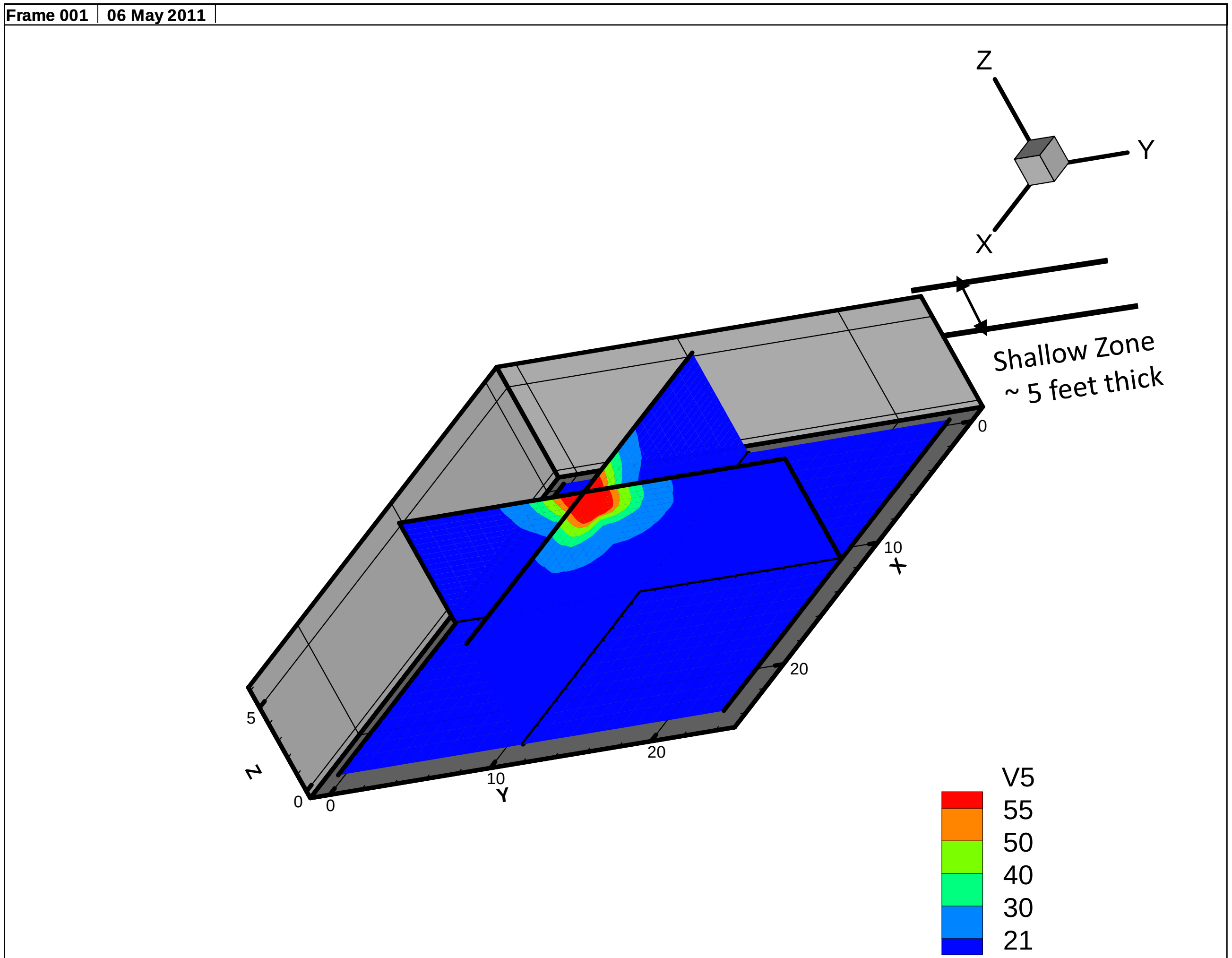
Standard Conditions: 68 °F, 14.7 psia, 36% RH (American Society of Mechanical Engineers [ASME] and Compressed Air and Gas Institute [CAGI])
The target soil temperature range is between 40 to 60 °C (104 to 140 °F)

Model Design: Model grid is an 80 feet x 80 feet area, by 20 feet deep. Three layers including a) shallow zone (fill/upper silty sand) 0-5 feet bgs, b) intermediate silty clay zone 5-10 feet bgs, and c) deep zone (lower silty sand) 10-15 feet bgs. One dual level AI/Steam injection well is located in the center of the model grid, and four dual level SVE extraction wells are located at the corners of the model grid (approximately 40 center to center well spacing). Simulations are performed assuming heating in one depth interval (i.e., shallow or deep) at a time.

Atmospheric/Barometric Pressure	14.70	psia
Manifold Injection Pressure	5.4	psig
Partial Pressure of Water Vapor at Standard Conditions	0.842	kPa
Water Vapor Mass Ratio at Standard Conditions	0.00521	kg/kg
Partial Pressure of Water Vapor at Saturated Conditions	2.338	kPa
Water Vapor Mass Ratio at Saturated Conditions	0.01469	kg/kg
Moist Air Density at Standard Conditions	1.200	kg/m^3
Air Density at Standard Conditions	1.204	kg/m^3

[1] = Water saturation pressures are from: http://www.engineeringtoolbox.com/water-vapor-saturation-pressure-d_599.htm

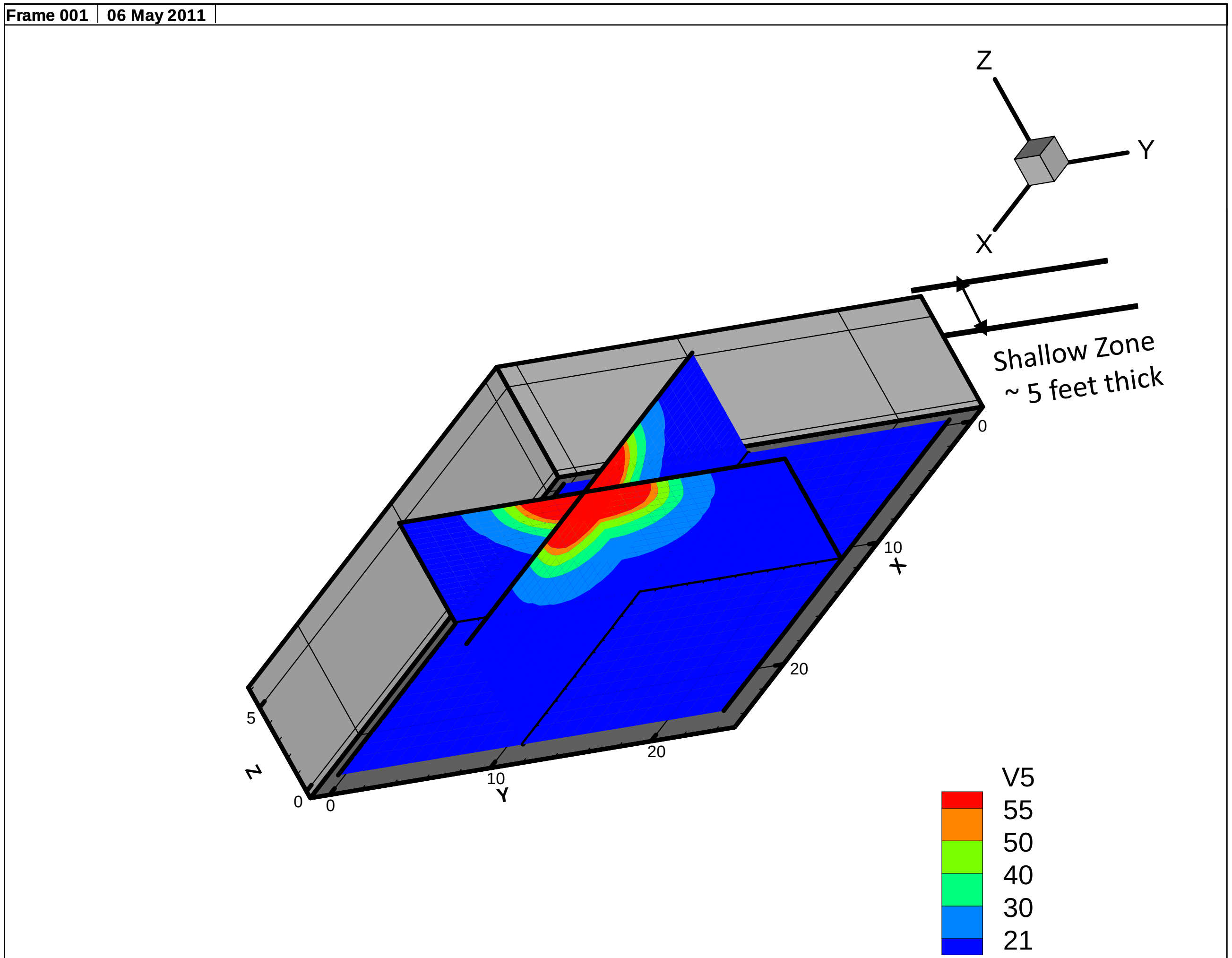
Simulation – 01A: 20% Steam (60C) at 50 scfm – 200 Days
Shallow Soil Zone – Temperature Distribution



Concrete Cap Heat Loss Coefficient = 2 W/m^2-K
Standard concrete cap 8" thick

Model Grid Scale in Meters (m)

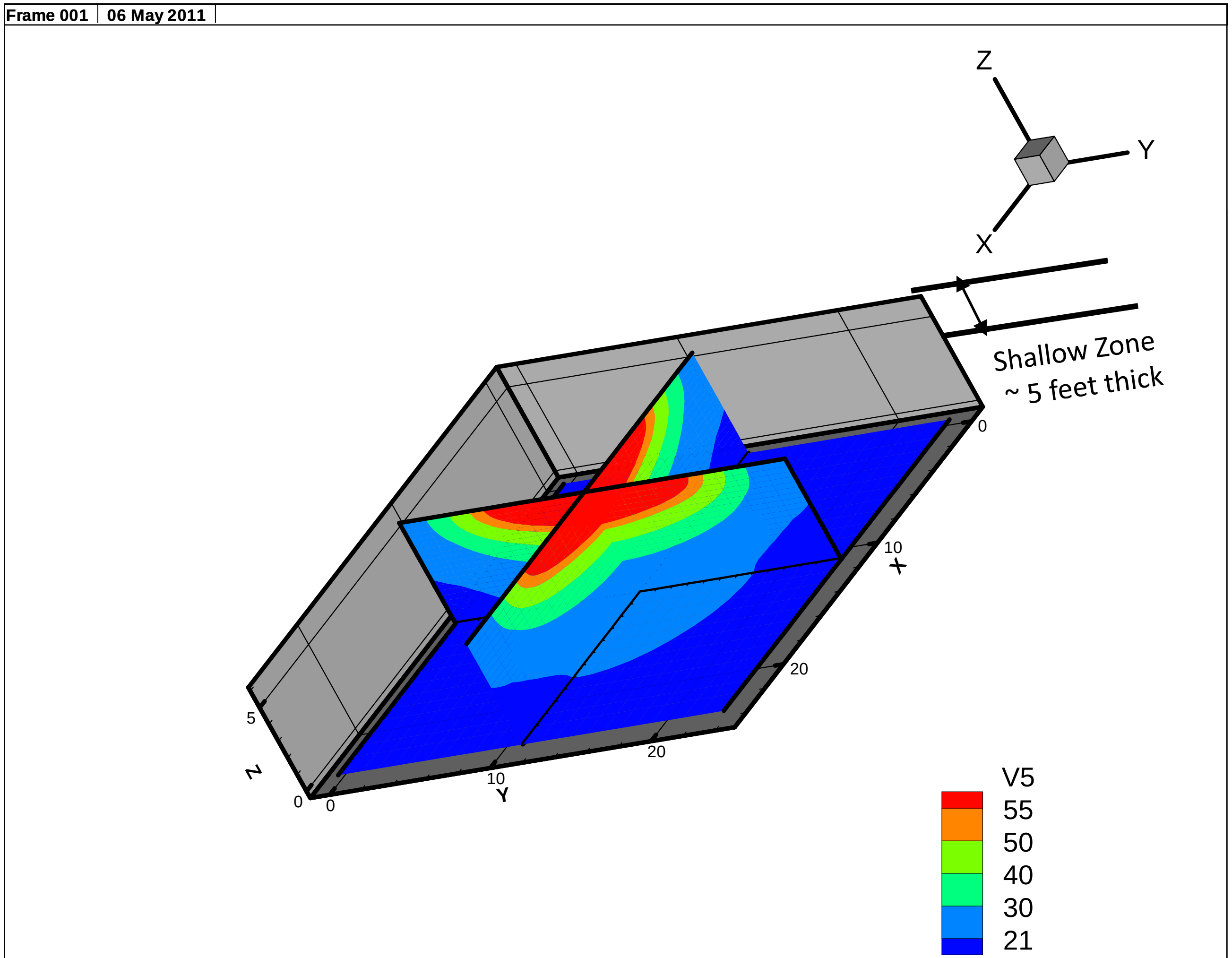
Simulation – 02A: 20% Steam (60C) at 50 scfm – No Surface Heat Loss – 10 Days
Shallow Soil Zone – Temperature Distribution



Assumes that there is no heat loss through the surface cap

Model Grid Scale in Meters (m)

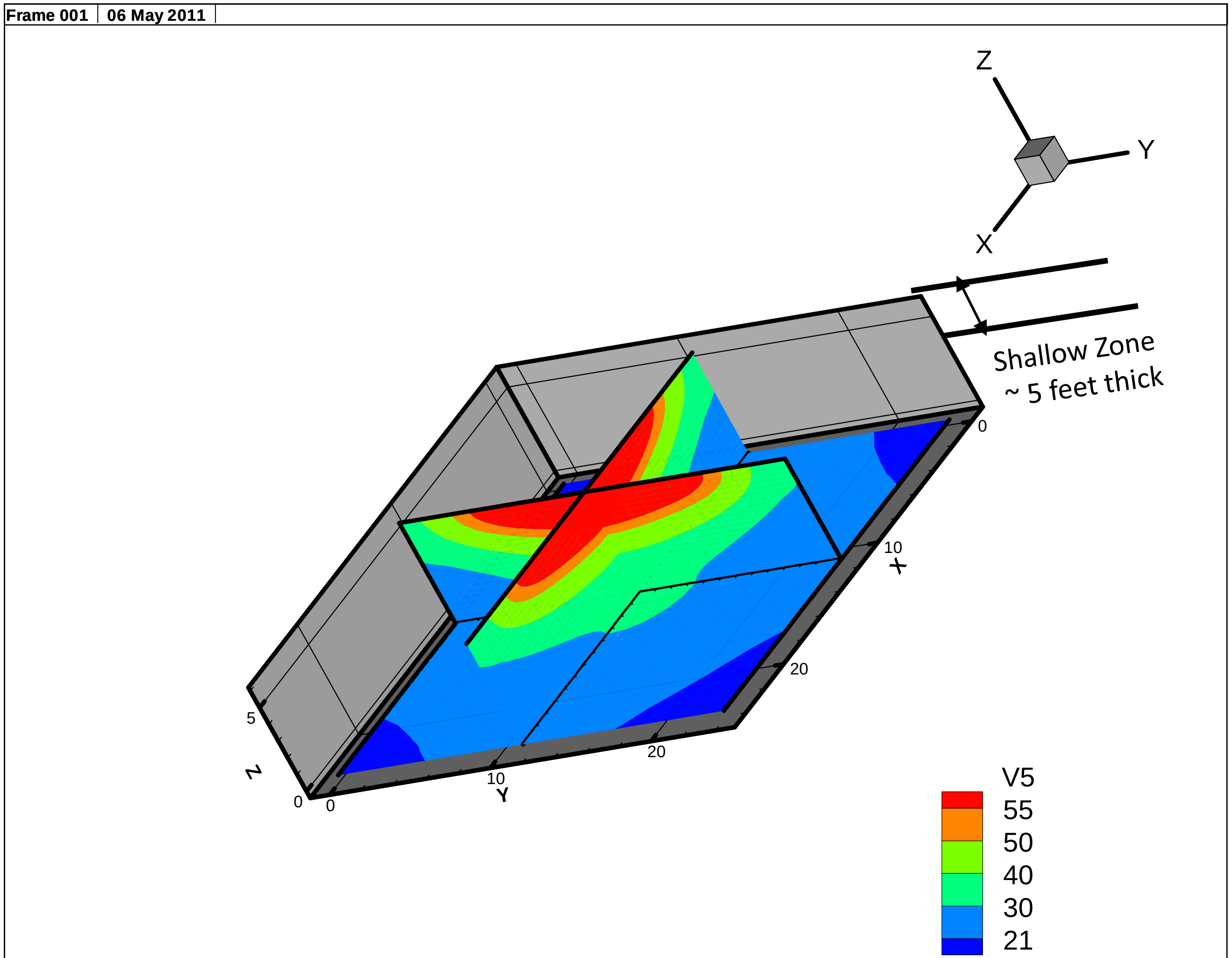
Simulation – 02B: 20% Steam (60C) at 50 scfm – No Surface Heat Loss – 50 Days
Shallow Soil Zone – Temperature Distribution



Assumes that there is no heat loss through the surface cap

Model Grid Scale in Meters (m)

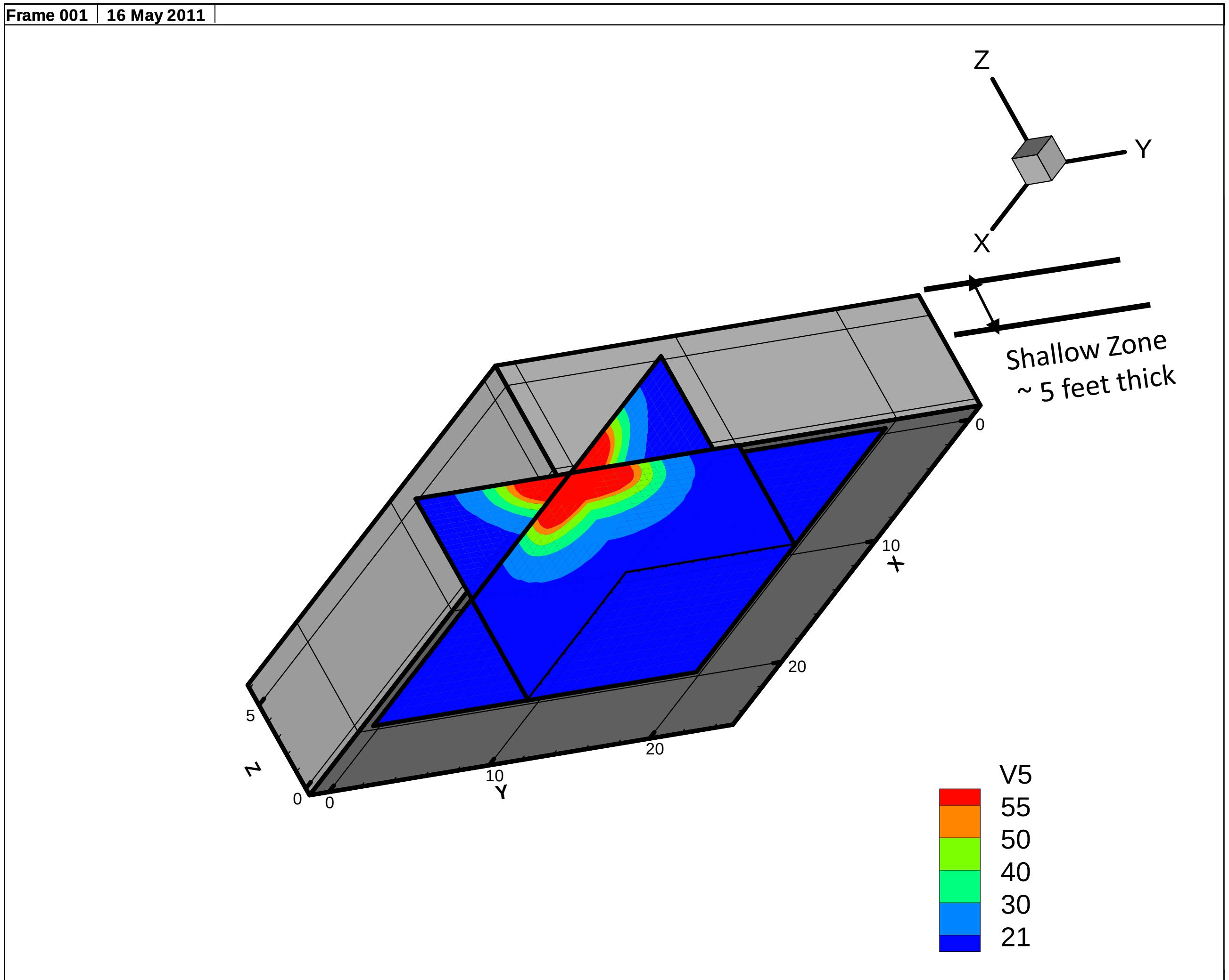
Simulation – 02C: 20% Steam (60C) at 50 scfm – No Surface Heat Loss – 100 Days
Shallow Soil Zone – Temperature Distribution



Assumes that there is no heat loss through the surface cap

Model Grid Scale in Meters (m)

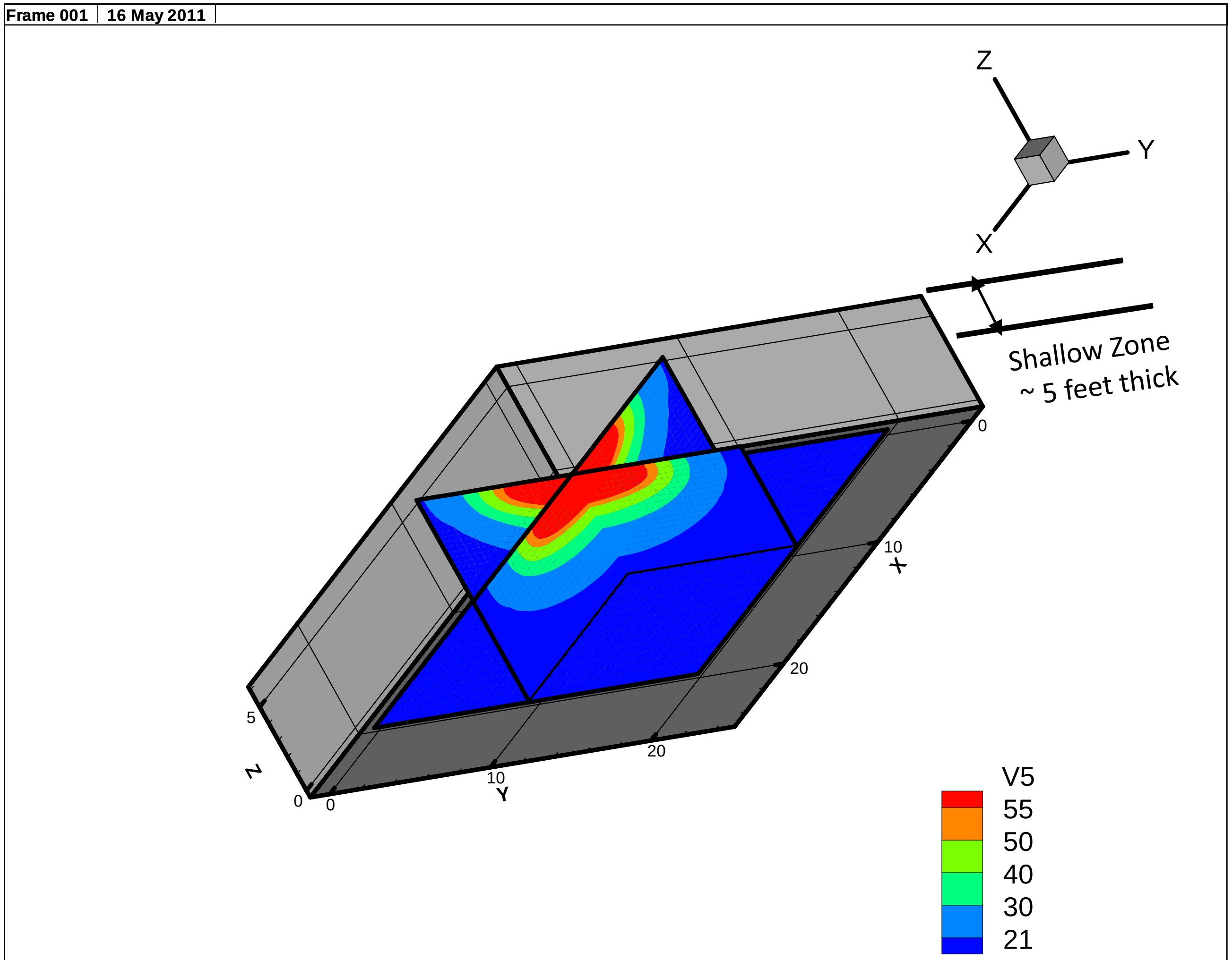
Simulation – 03A: 20% Steam (60C) at 50 scfm – 10 Days
Shallow Soil Zone – Temperature Distribution



Water table at 15 ft bgs
Elastizell Thermal Cap (12" Thick)

Model Grid Scale in Meters (m)

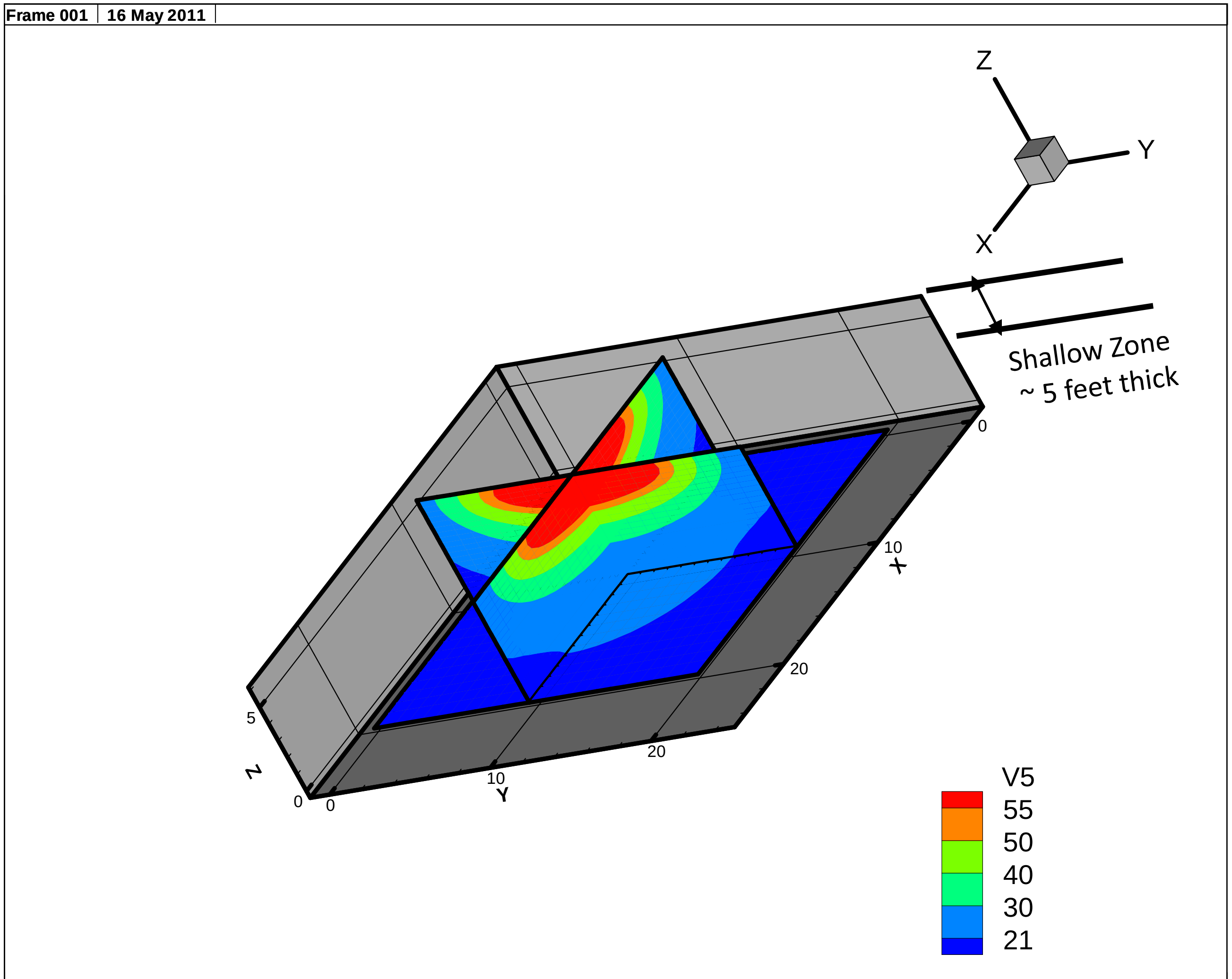
Simulation – 03B: 20% Steam (60C) at 50 scfm – 20 Days
Shallow Soil Zone – Temperature Distribution



Water table at 15 ft bgs
Elastizell Thermal Cap (12” Thick)

Model Grid Scale in Meters (m)

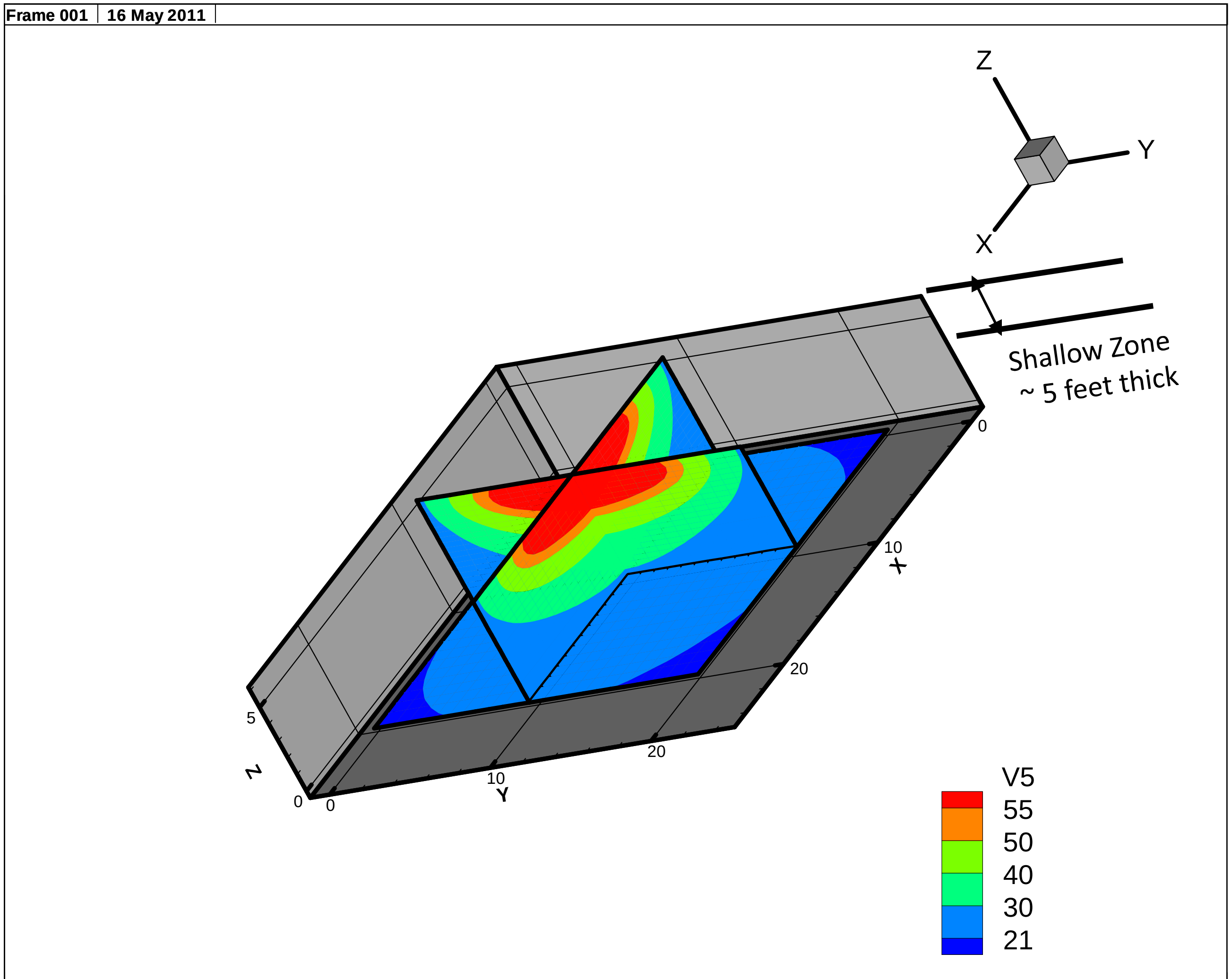
Simulation – 03C: 20% Steam (60C) at 50 scfm – 50 Days
Shallow Soil Zone – Temperature Distribution



Water table at 15 ft bgs
Elastizell Thermal Cap (12” Thick)

Model Grid Scale in Meters (m)

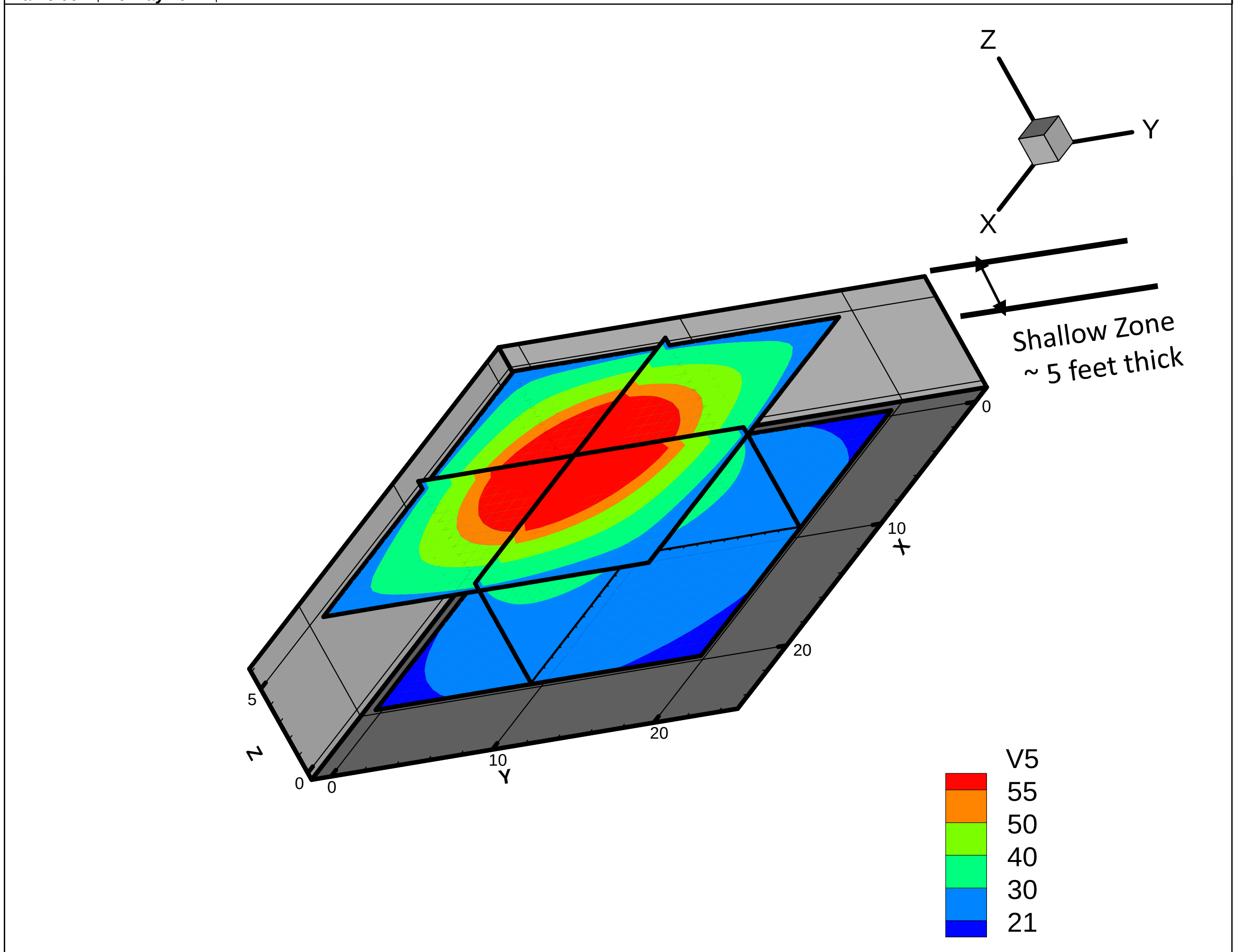
Simulation – 03D.i: 20% Steam (60C) at 50 scfm – 100 Days
Shallow Soil Zone – Temperature Distribution



Water table at 15 ft bgs
Elastizell Thermal Cap (12” Thick)

Model Grid Scale in Meters (m)

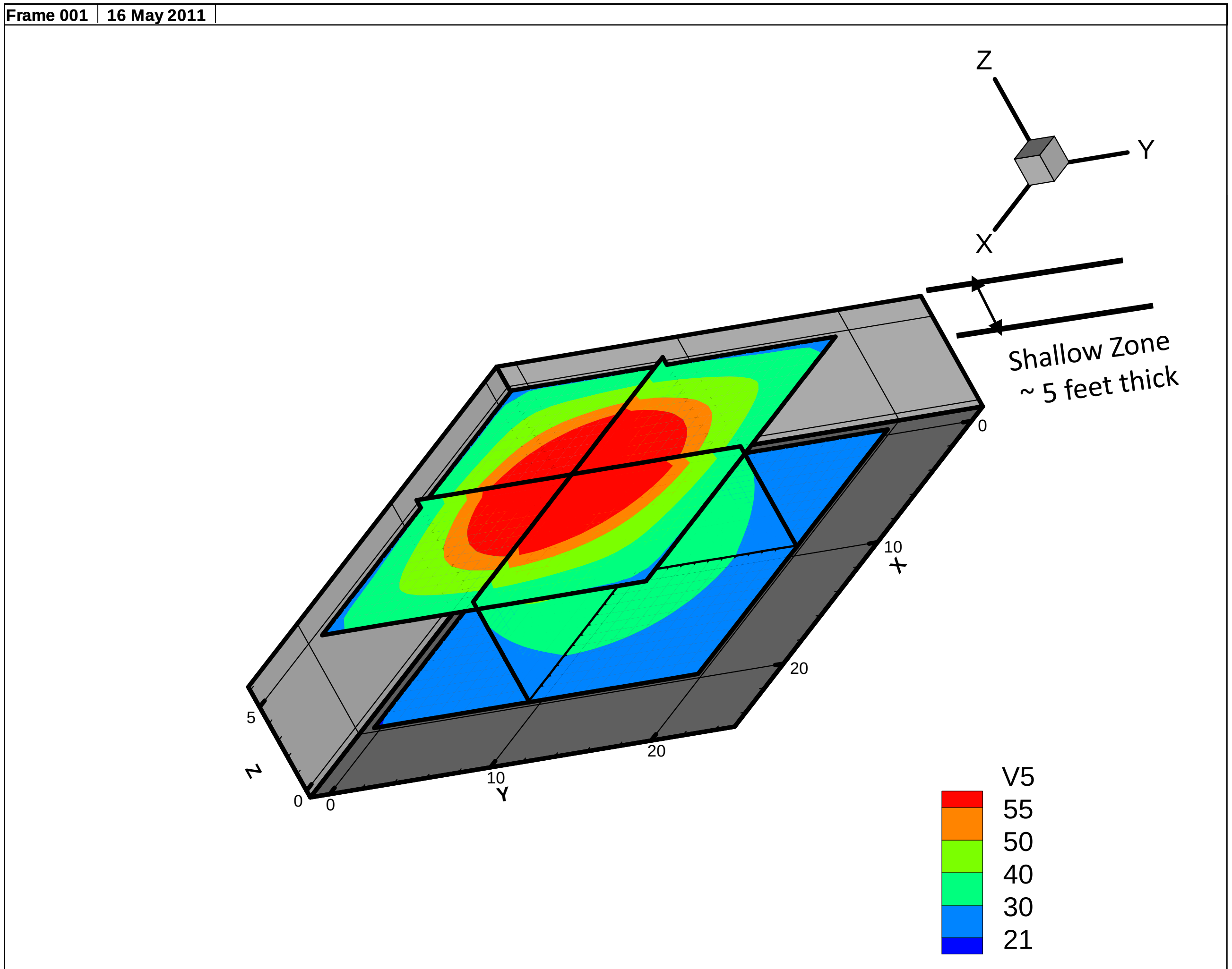
Simulation – 03D.ii: 20% Steam (60C) at 50 scfm – 100 Days
Shallow Soil Zone – Temperature Distribution (Heat distribution plotted at 3 feet bgs)



Water table at 15 ft bgs
Elastizell Thermal Cap (12” Thick)

Model Grid Scale in Meters (m)

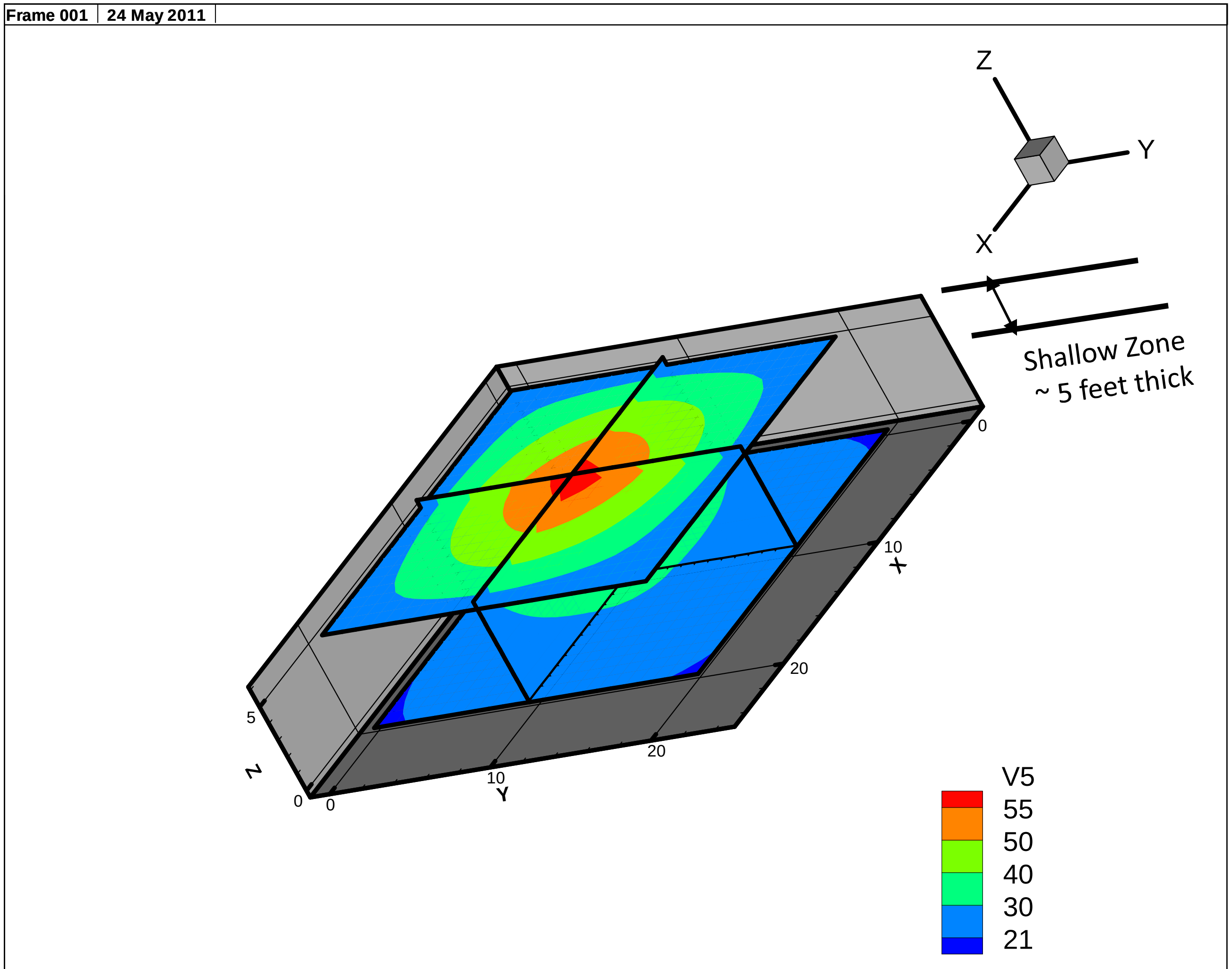
Simulation – 03E: 20% Steam (60C) at 50 scfm – 200 Days
Shallow Soil Zone – Temperature Distribution (Heat distribution plotted at 3 feet bgs)



Water table at 15 ft bgs
Elastizell Thermal Cap (12" Thick)

Model Grid Scale in Meters (m)

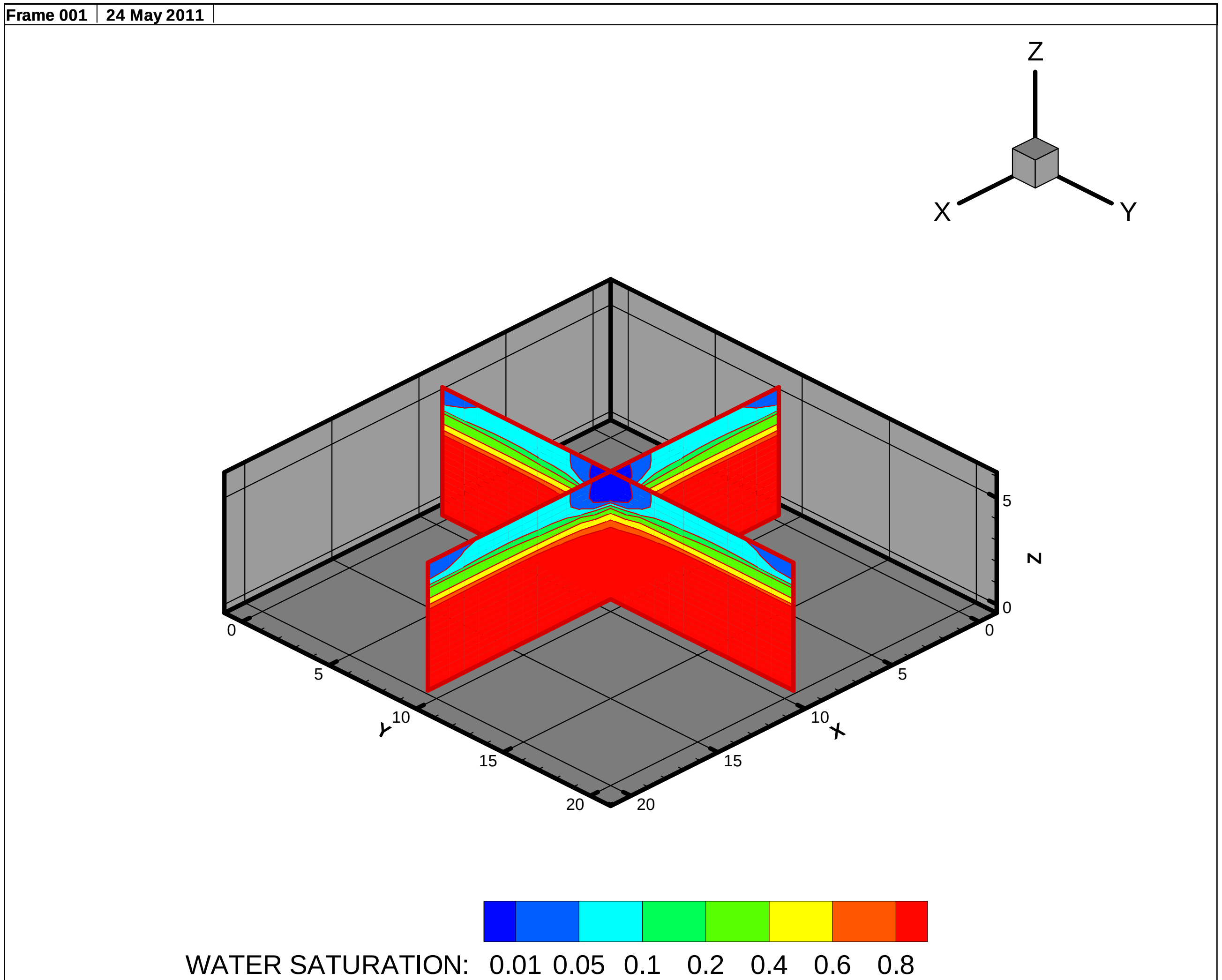
Simulation – 04A: 10% Steam (100C) at 50 scfm – 200 Days
Shallow Soil Zone – Temperature Distribution (Heat distribution plotted at 3 feet bgs)



Water table at 10 ft bgs (groundwater velocity = 10 ft/year)
Elastizell Thermal Cap (12” Thick)

Model Grid Scale in Meters (m)

Simulation – 04B: 10% Steam (100C) at 50 scfm – 200 Days
Shallow Soil Zone – Water Saturations

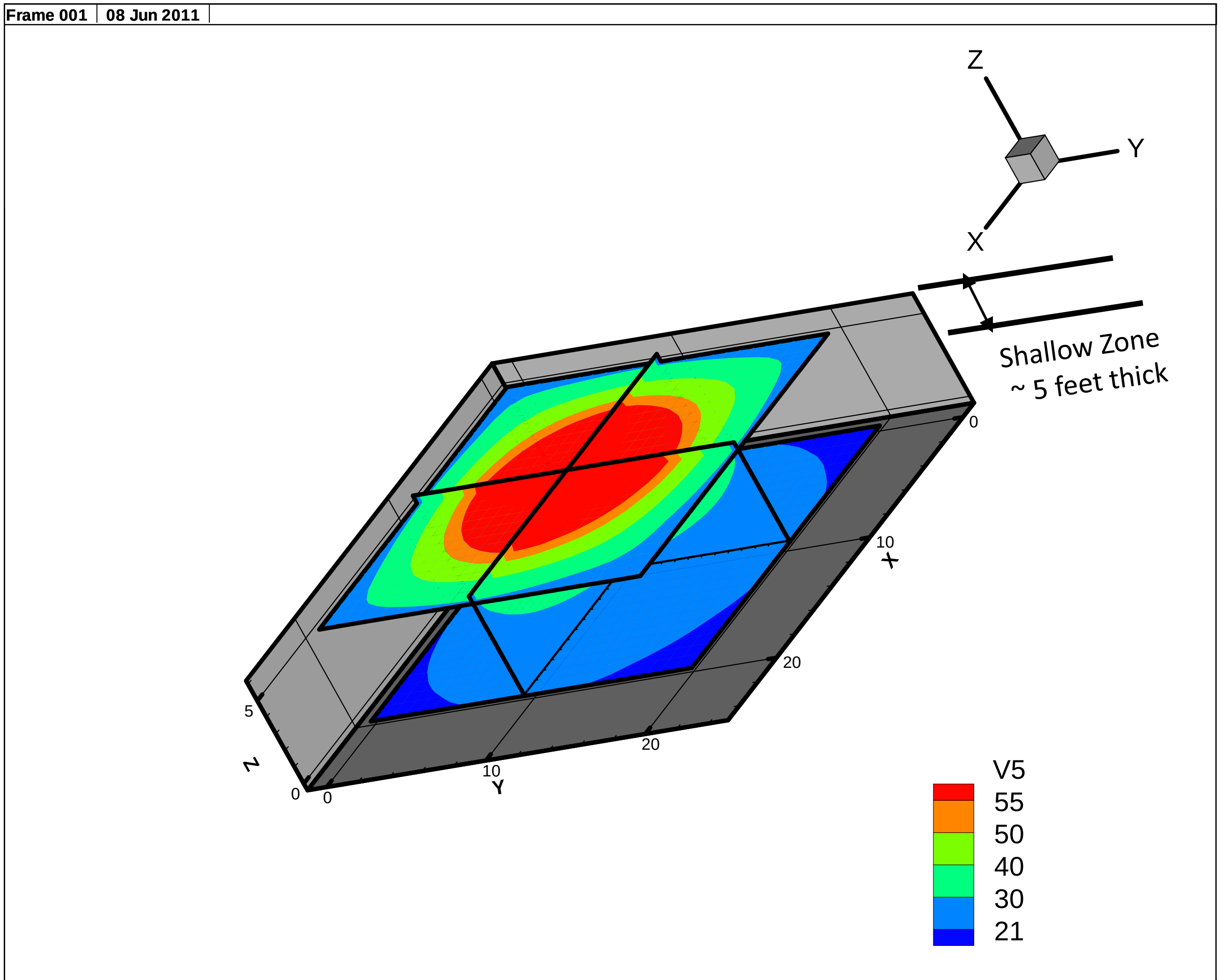


Water table at 10 ft bgs (groundwater velocity = 10 ft/year)

Elastizell Thermal Cap (12” Thick)

Model Grid Scale in Meters (m)

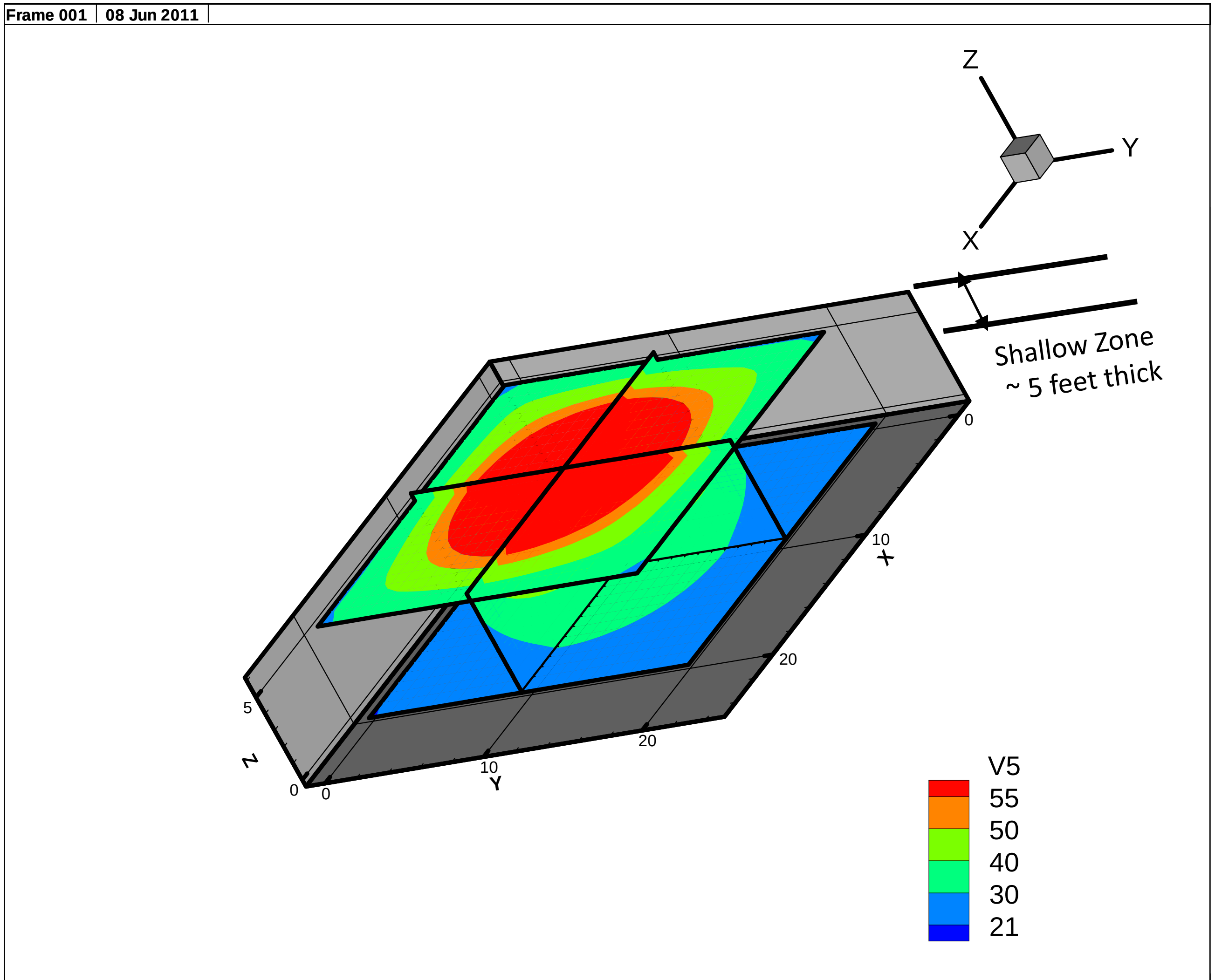
Simulation – 05A: 20% Steam (100C) at 50 scfm – 100 Days
Shallow Soil Zone – Temperature Distribution (Heat distribution plotted at 3 feet bgs)



Water table at 10 ft bgs (groundwater velocity = 10 ft/year)
Elastizell Thermal Cap (12” Thick)

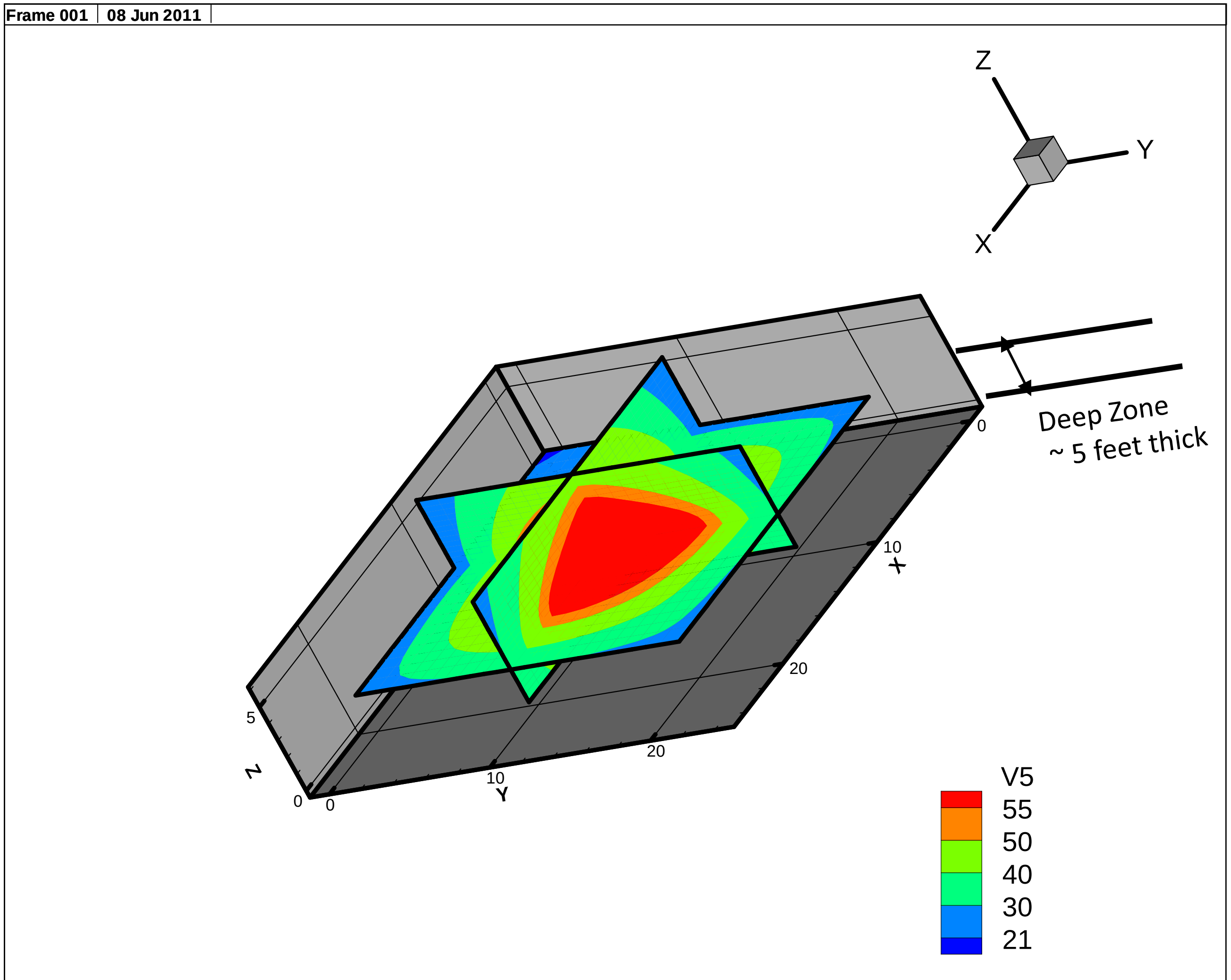
Model Grid Scale in Meters (m)

Simulation – 05B: 20% Steam (100C) at 50 scfm – 200 Days
Shallow Soil Zone – Temperature Distribution (Heat distribution plotted at 3 feet bgs)



Water table at 10 ft bgs (groundwater velocity = 10 ft/year)
Elastizell Thermal Cap (12” Thick)
Model Grid Scale in Meters (m)

Simulation – 6A: 20% Steam (100C) at 50 scfm – 200 Days
Deep Soil Zone – Temperature Distribution



Water table at 15 ft bgs (groundwater velocity = 10 ft/year)
Elastizell Thermal Cap (12" Thick)

Model Grid Scale in Meters (m)

Appendix C

T-SVE Shutdown Protocol

To:	Jerry Rinaldi (Solutia)	**Date:**	November, 2011
From:	Scott Crawford (XDD)	**Cc:**	Mike Marley (XDD) John Conner (GSI) XDD File (p1103)
RE:	**Protocol for Completing Thermally Enhanced Soil Vapor Extraction Operations and Potential Transitioning to Bioventing Mode** **Former Chlorobenzene Process Area** **Solutia Inc., W.G. Krummrich Facility, Sauget, Illinois**		

Dear Mr. Rinaldi,

XDD, LLC (XDD) has prepared this protocol to determine when it is appropriate to cease Thermally Enhanced Soil Vapor Extraction (T-SVE) operations in the Chlorobenzene Process Area (CPA) area at the Solutia Inc. (Solutia) W.G. Krummrich facility. The objective will be to assess whether it is necessary to address any residual impacts remaining within silty sand and intermediate silty clay units at the completion of the T-SVE operations.

The steps in this protocol will provide the basis for making the recommendation, which will be approved by the United States Environmental Protection Agency (U.S. EPA), for shutdown of T-SVE or making the transition to bioventing (BV). T-SVE operations will continue in the CPA area until U.S. EPA approval of the corresponding recommendation to shut down or transition to BV.

It is proposed that T-SVE operations would be considered complete when the mass removal rate of the T-SVE system reaches an asymptotic condition. Asymptotic conditions would be based upon the observation that the contaminant of concern (COC) vapor mass removal rate is less than 10% of the observed peak rate for at least seven consecutive calendar days.

The decision to shut down T-SVE operations and potentially transition to the BV mode is recommended to be based upon the following steps:

1. **Process Vapor Monitoring** - Conduct performance monitoring of T-SVE operations to assess the COC mass removal rate and cumulative COC mass removal in the vapor phase. This includes:
    a. Measurement of COC concentrations in the T-SVE well field vapor stream.
    b. Measurement of the total T-SVE well field flowrate.
    c. The COC mass removal rates for each monitoring event will be calculated based upon the COC vapor concentration and the T-SVE flowrate.

   d. The cumulative COC mass removed will be calculated based upon the average COC mass removal rate and the length of time elapsed between each monitoring event.
   e. Process vapor monitoring would be conducted initially on a weekly basis, and this frequency would be reduced as vapor concentrations and mass removal rates stabilize.
   f. The cumulative COC mass removed as vapor will be plotted and provided to U.S. EPA in quarterly status updates.

2. **<u>Assess Asymptotic Conditions</u>** - Identify when asymptotic mass removal rate conditions are achieved:
   a. The initial peak COC vapor concentrations observed at start-up of the T-SVE system will be associated with the flushing of "static-equilibrium" soil gas concentrations. These initial peak level concentrations tend to decline rapidly after start-up as the initial pore volumes of soil gas are removed.
   b. For the purposes of establishing a representative baseline mass removal rate for the T-SVE system, the average mass removal rate will be calculated based on a one month period, and the averaging period will begin when a stable soil temperature between 40 and 60 degrees Celsius (deg. C) is achieved.
   c. T-SVE operations will be considered to have achieved asymptotic conditions when mass removal rates have been reduced to 10% of the baseline mass removal rate and remain at this level or lower for a period greater than seven days.
   d. The mass removal rate will not be considered to be "asymptotic" if the reason for the decrease in mass removal rates appears to be related to groundwater table elevations rising and blocking the T-SVE well screen, or if subsurface temperatures drop below the target soil temperature range.

3. **<u>Soil Sampling</u>** - Conduct soil sampling to assess reductions in soil concentrations and soil COC mass during T-SVE operations:
   a. Soil sampling is to be conducted on an annual basis (except within the intermediate silty clay which is proposed to be conducted once near the completion of T-SVE operations). The final soil sampling event would be conducted after asymptotic COC mass removal rates are achieved (see Step #2 above).
   b. Initial COC mass estimates in the CPA area have been provided in Table D-3 of the *Former Chlorobenzene Process Area Characterization Report*. The estimated mass of benzene and chlorinated benzenes is 440,000 pounds.
   c. Soil COC mass remaining will be calculated following each annual soil sampling event and compared to the initial mass estimates to estimate percent mass reduction.
   d. The COC mass reduction on the soils will also be compared to the cumulative COC mass removed based on vapor concentration data (see Step #1 above).

4. **Assess COC Mass Remaining on Soils** – Upon reaching an asymptotic condition, evaluate the impact, if any, of residual COC mass remaining on soils:
    a. Modeling will be conducted to evaluate potential impact to groundwater posed by the remaining COC mass in the unsaturated zone. Note that potential impacts to groundwater from COC mass within the underlying saturated zone (15 to 30 foot interval) will be evaluated concurrently during the Enhanced Aerobic Bioremediation (EABR) performance evaluations.
    b. Residual soil concentrations will also be evaluated to determine if there are any potential human health risks and if these are addressed by institutional controls.
    c. If a. or b. above suggest the need for further action, an evaluation to determine if BV will address the residual soil concentrations will be conducted.

5. **Recommendation for Shutdown or Transition to BV** – Prepare a report for U.S. EPA to recommend whether to shut down or transition from T-SVE to BV:
    a. Based on the data collection and evaluations conducted in Step #1 through #4, prepare a report for U.S. EPA to confirm that asymptotic conditions have been achieved and residual COC mass remaining does not pose unacceptable risk to groundwater or human health.
    b. Upon U.S. EPA's agreement, the T-SVE system would be either shut down or transitioned into the BV phase of operations (Step #6 below). Note that it will be appropriate to recommend shutdown of portions of the T-SVE system in a phased manner as sub-areas and/or specific depth intervals meet the performance criteria. This will be evaluated during regular system optimization events.

6. **Transition to BV Operations** – In accordance with Step #5 above, after shutdown of T-SVE operations, BV may be conducted to address COC mass flux from the intermediate silty clay unit. If so, BV will provide some additional reduction of the residual COC mass remaining within the upper and lower silty sand units. Annual sampling will be conducted within the intermediate silty clay unit to assess COC mass reduction (as compared to "baseline" soil concentrations at the completion of the T-SVE phase of operations).

7. **Completion of BV Operations** - Based on the performance of BV within the intermediate silty clay unit, a recommendation will be made to U.S. EPA regarding shutdown of BV operations.
    a. BV is not expected to yield appreciable results after one year. If, after two years of BV, no significant reduction in COC mass has occurred within the intermediate silty clay, it will be recommended to shut down the BV operations.
    b. COC mass reduction in the intermediate silty clay unit will be assessed annually using the soil sampling data. An assessment will be made regarding the benefit, if any, of ongoing BV operation.

c. Prior to shutdown of BV operations, the impact, if any, of residual COC mass will be assessed:
    i. Modeling will be conducted to evaluate potential impact to groundwater posed by the remaining COC mass in the intermediate silty clay zone.
    ii. Residual soil concentrations will also be evaluated to determine if there are any potential human health risks and if these are addressed by institutional controls.

d. If either c.i. or c.ii. above suggests the need, an evaluation will be conducted to determine additional actions to address the remaining residual risks. Additional actions may include monitored natural attenuation (MNA) or additional institutional controls.

e. Upon approval by U.S. EPA, the BV operations will be shut down. Note that it will be appropriate to recommend shutdown of portions of the BV system in a phased manner as sub-areas and/or specific depth intervals meet the performance criteria.