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McDonald, Jeffrey

From: Gilmore, Tyler J [Tyler.Gilmore@pnnl.gov]
Sent: Friday, March 07, 2014 10:06 AM
To: McDonald, Jeffrey; Bayer, MaryRose
Cc: Bonneville, Alain; Greenhagen, Andrew
Subject: Re: AoR Determination
Attachments: Birkholzer and AOR-Eqn 1 and 2 Pressure-Worksheet-3-3-14.xlsx

Morning Jeff,
Attached are the Birkholzer calculations.
Tyler

From: <McDonald>, Jeff McDonald <mcdonald.jeffrey@epa.gov>
Date: Friday, March 7, 2014 6:36 AM
To: Tyler Gilmore <tyler.gilmore@pnnl.gov>, "Bayer, MaryRose" <Bayer.MaryRose@epa.gov>
Cc: Alain HR Bonneville <alain.bonneville@pnnl.gov>, "Greenhagen, Andrew" <Greenhagen.Andrew@epa.gov>
Subject: RE: AoR Determination

Tyler,

Thanks. We're going to talk about this today in our office.

Are you sending the Birkholzer calculations also this morning?

Thanks,

Jeff

Jeffrey R. McDonald, Geologist
Underground Injection Control Branch
U.S. EPA - Region 5
(312) 353-6288
mcdonald.jeffrey@epa.gov

From: Gilmore, Tyler J <Tyler.Gilmore@pnnl.gov>
Sent: Thursday, March 06, 2014 10:54 PM
To: McDonald, Jeffrey; Bayer, MaryRose
Cc: Bonneville, Alain
Subject: RE: AoR Determination

Corrected Area

From: Gilmore, Tyler J
Sent: Thursday, March 06, 2014 8:07 PM
To: Jeff McDonald (mcdonald.jeffrey@epa.gov); Bayer, MaryRose
Cc: Bonneville, Alain
Subject: AoR Determination

Jeff and Molly,
We do not believe there is a technical basis for establishing the Area of Review (AoR) based on the maximum extent of the 10 psi pressure front, however, we do recognize EPA's determination today that this will be the basis for AoR in the draft permit. We are now focused on how we can reasonably meet this determination.

The AoR based on the 10psi pressure front represents an area of approximately **2800 sq miles** and presents a number of practical challenges. As you know the regulations require that we provide a map showing the injection well for which a permit is sought and the applicable area of review consistent with 146.84. Within the area of review, the **map must show number or name, and location of all injection wells, producing wells,abandoned wells, plugged wells or dry holes, deepstratigraphic boreholes, State- or EPA-approved subsurface cleanup sites, surface bodies of water,springs, mines (surface and subsurface), quarries, water wells, other pertinent surface featuresincluding structures intended for human occupancy, State, Tribal, and Territory boundaries, androads. The map should also show faults, if known or suspected. Only information of public record isrequired to be included on this map.**

We request that we may provide this information either through maps or by reference. For example providing an exhaustive list of "structures intended for human occupancy" is not practical, especially when several towns and villages are included in the resulting AoR. We can however, provide this information by reference by identifying the county assessors offices. Please advise us whether this approach will meet the intent of the regulations.

Respectfully
Tyler

Depth ft, bgs	Total Pressure/Depth Data Set psi (gage)		
1134.03	455.68	Silurian LS MDT	slope
1134.97	456.06		intercept
1930.99	786.90	St. Peter MDT	Profile Plots
1930.06	784.34		500.00
1781.99	718.16		4500.00
1748.96	703.39		
4034.01	1775.56	Mt. Simon MDT	Top of Mount Simon
4033.95	1775.48		Top of Elmhurst
4096.48	1803.62		Top of Lombard
4116.02	1812.85		Top of Potosi
4116.98	1813.04		Bot. of Potosi
3898.44	1708.33	Mt. Simon packer tests	Bot. of St. Peter
4192.96	1846.98		
4235.24	1864.10	Mt. Simon GM11B	
4155.24	1829.00	GM12	
4121.55	1815.60	GM13	

Press/Depth Regression Equations

Total	Mt. Simon
0.46182	0.46167
-90.4630	-88.4401
140.4454	142.3960238
1987.7124	1989.085036

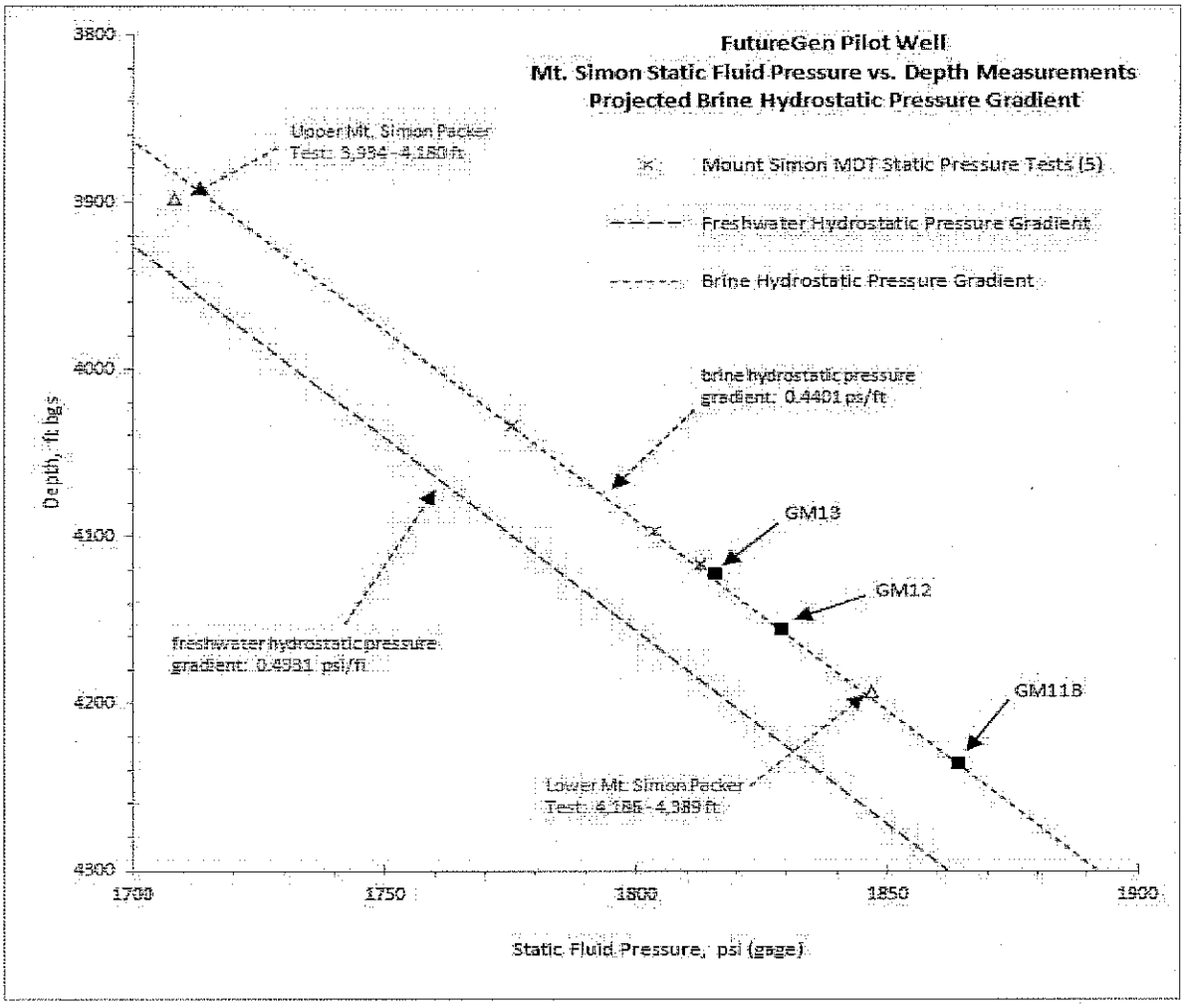
Depth, ft bgs	Calculated P (Total Reg.) psig	Calculated P (Mt.Simon Reg.) psig
3904	1712.47	1713.93
3838	1681.99	1683.46
3581	1563.30	1564.81
2796	1200.78	1202.40
3072	1328.24	1329.82
1942	806.39	808.13

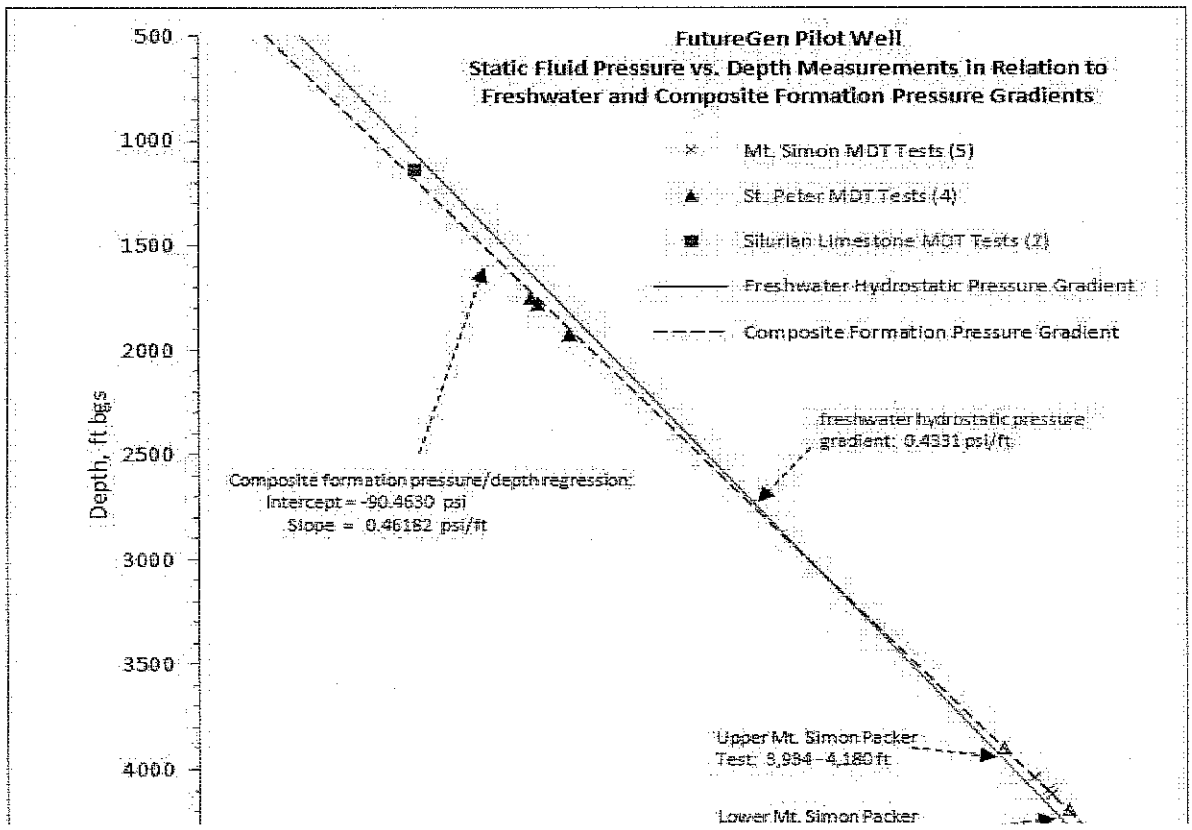
Schlumberger, Inc., 2011a. "Battelle/FutureGen#1, Morgan County Illinois: Modular Dynamics Formation Tester: Pressure/Sampling/Gamma";
1 Schlumberger processed/analysis log
Survey Date - October 27, 2011; PDF File Name: BXDS_00005_BATTELLE_FUTUREGEN_1_MDT_Combined.PDF

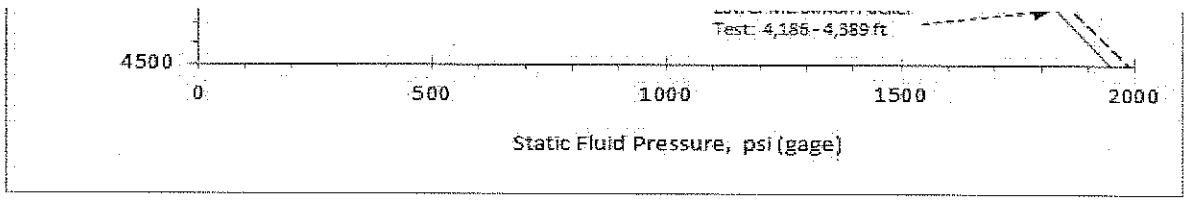
Schlumberger, Inc., 2011b. "FutureGen Industrial Alliance/FutureGen 2.0 No.1, Morgan County Illinois: Modular Dynamics Formation Tester:
2 Pressure/Sampling/Gamma"; Schlumberger processed/analysis log
Survey Date - December 14, 2011; Schlumberger PDS File Name: BPD8_35_Futuregen2_1_run4G_MDT_Combined.pds
Kelley ME, MA Moody, ER Zeller, WH Rike, NA Berelsman, C McNeil, J Holley, C Sullivan, D Appriou, FA Spane, JA Horner, and TJ Gilmore. 2012.
3 "Borehole Completion and Characterization

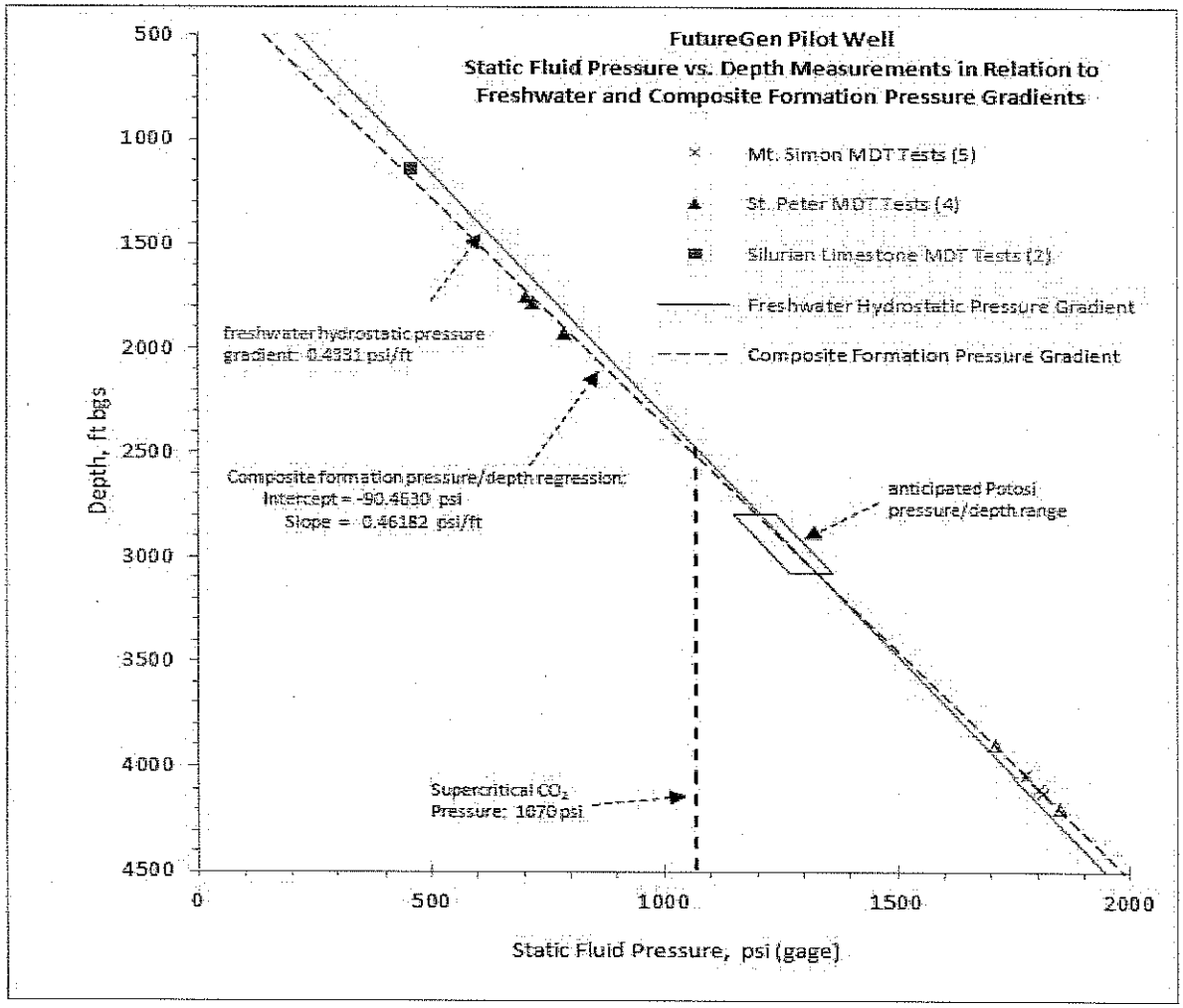
Report for the Stratigraphic Well, Morgan County, Illinois.", FGN-RPT-015/PNWD-4343, report prepared by Pacific Northwest National Laboratory, Richland WA for FutureGen Industrial Alliance, Inc.
Birkholzer JT, JP Nicot, CM Oldenburg, Q Zhou, S Kraemer, and K Bandilla. 2011. "Brine flow up a well caused by pressure perturbation from geologic
4 carbon sequestration:
static and dynamic evaluations." International Journal of Greenhouse Gas Control, doe:10.1016/j.ijggc.2011.01.003.

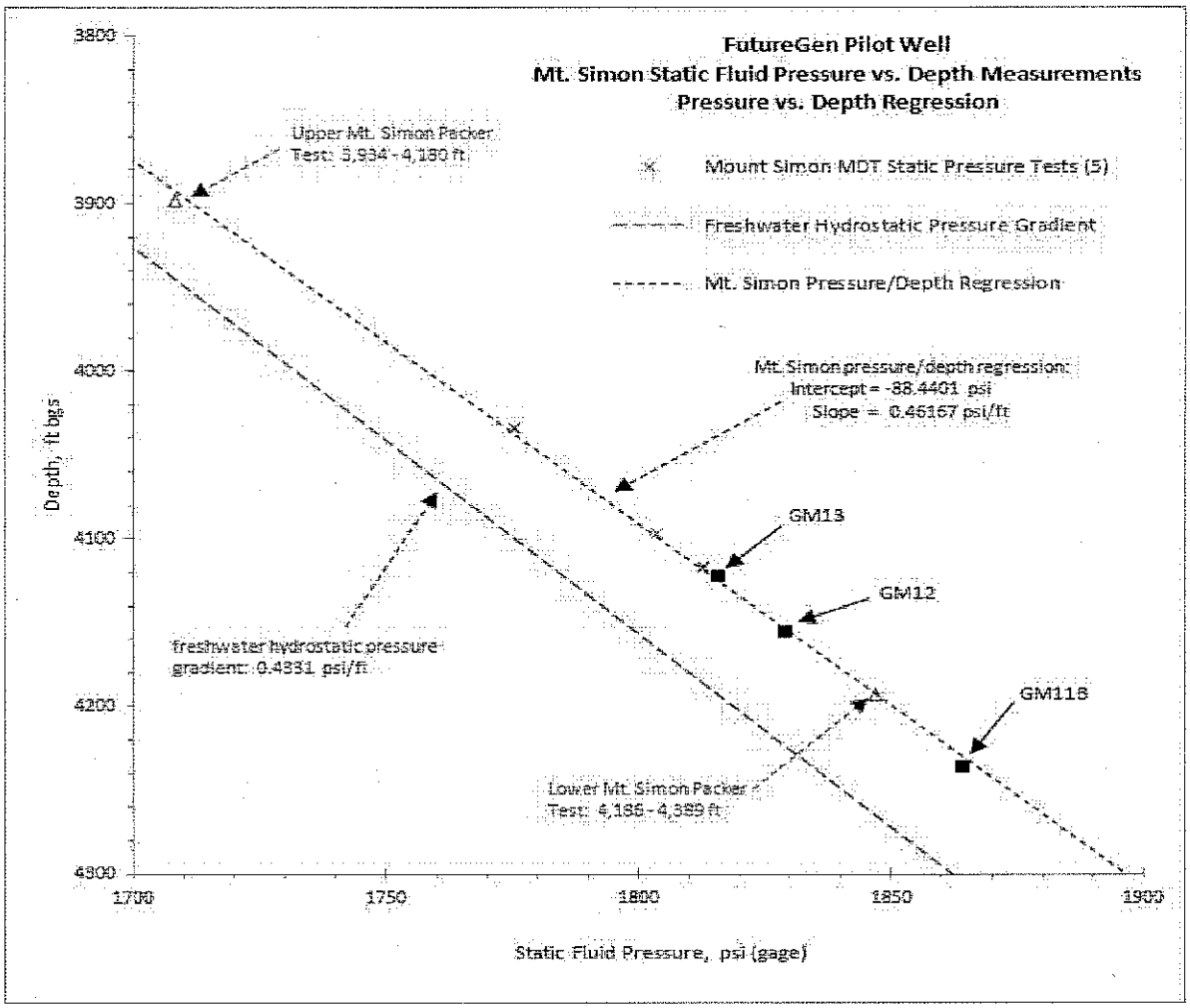
Spane FA and RB Mercer. 1985. "HEADCO: a program for converting observed water levels and pressurem measurementsto formation pressure
5 and standard hydraulic head."
RHO-BW-ST-71P, Rockwell Hanford Operations, Richland, WA.

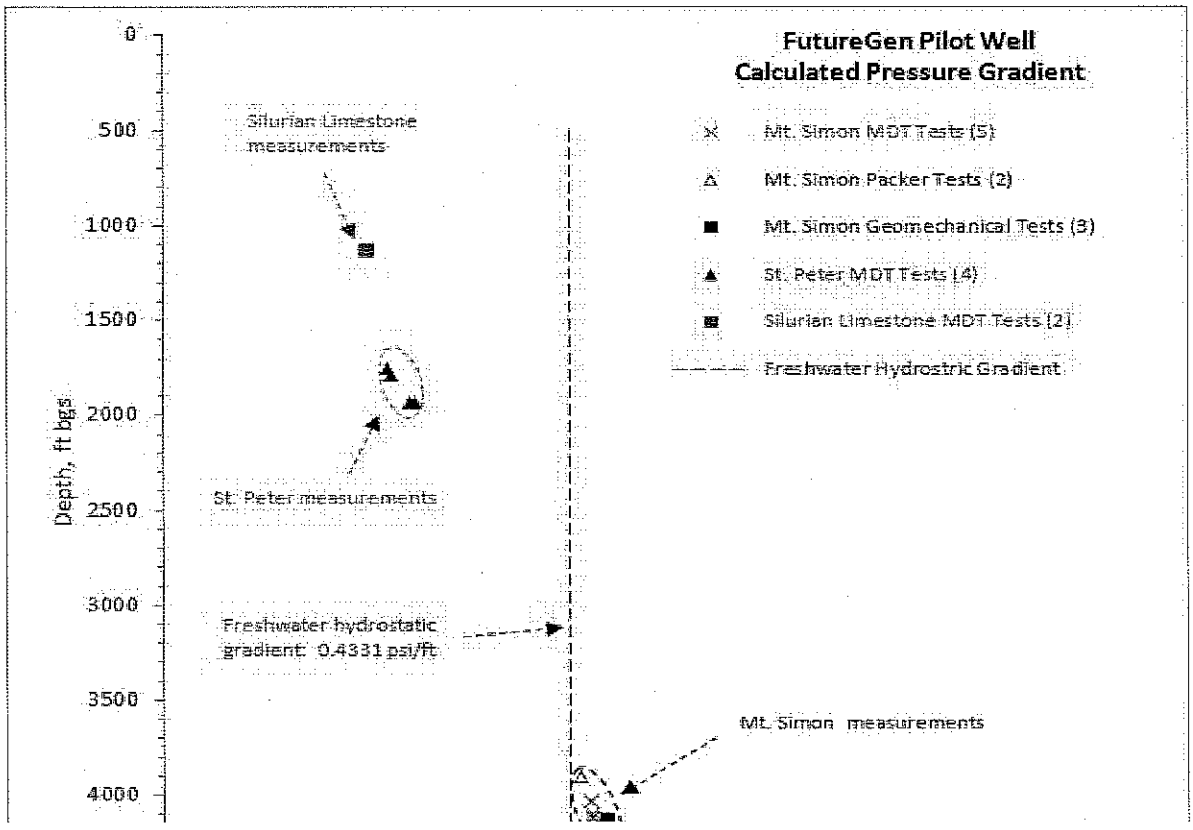

FutureGen Pilot Well
Mt. Simon Static Fluid Pressure vs. Depth Measurements
Projected Brine Hydrostatic Pressure Gradient
Upper Mt. Simon Packer
Test: 3,934 - 4,180 ft
Mount Simon MDT Static Pressure Tests (5)
Freshwater Hydrostatic Pressure Gradient
Brine Hydrostatic Pressure Gradient
brine hydrostatic pressure
gradient: 0.4401 psi/ft
GM13
GM12
GM11B
freshwater hydrostatic pressure
gradient: 0.4331 psi/ft
Lower Mt. Simon Packer
Test: 4,186 - 4,389 ft
Depth, ft bgs
3800
3900
4000
4100
4200
4300
1700
1750
1800
1850
1900
Static Fluid Pressure, psi (gage)

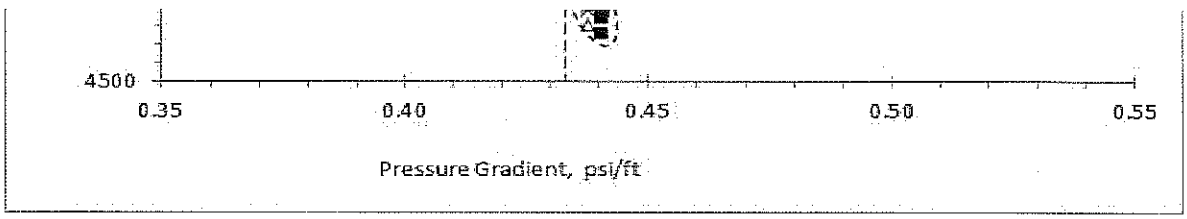

FutureGen Pilot Well
Static Fluid Pressure vs. Depth Measurements in Relation to
Freshwater and Composite Formation Pressure Gradients
Mt. Simon MDT Tests (5)
St. Peter MDT Tests (4)
Siturian Limestone MDT Tests (2)
Freshwater Hydrostatic Pressure Gradient
Composite Formation Pressure Gradient
freshwater hydrostatic pressure
gradient: 0.4331 psi/ft
Composite formation pressure/depth regression:
Intercept = -90.4630 psi
Slope = 0.46182 psi/ft
Upper Mt. Simon Packer
Test: 3,934 - 4,180 ft
Lower Mt. Simon Packer
Depth, ft bgs
500
1000
1500
2000
2500
3000
3500
4000

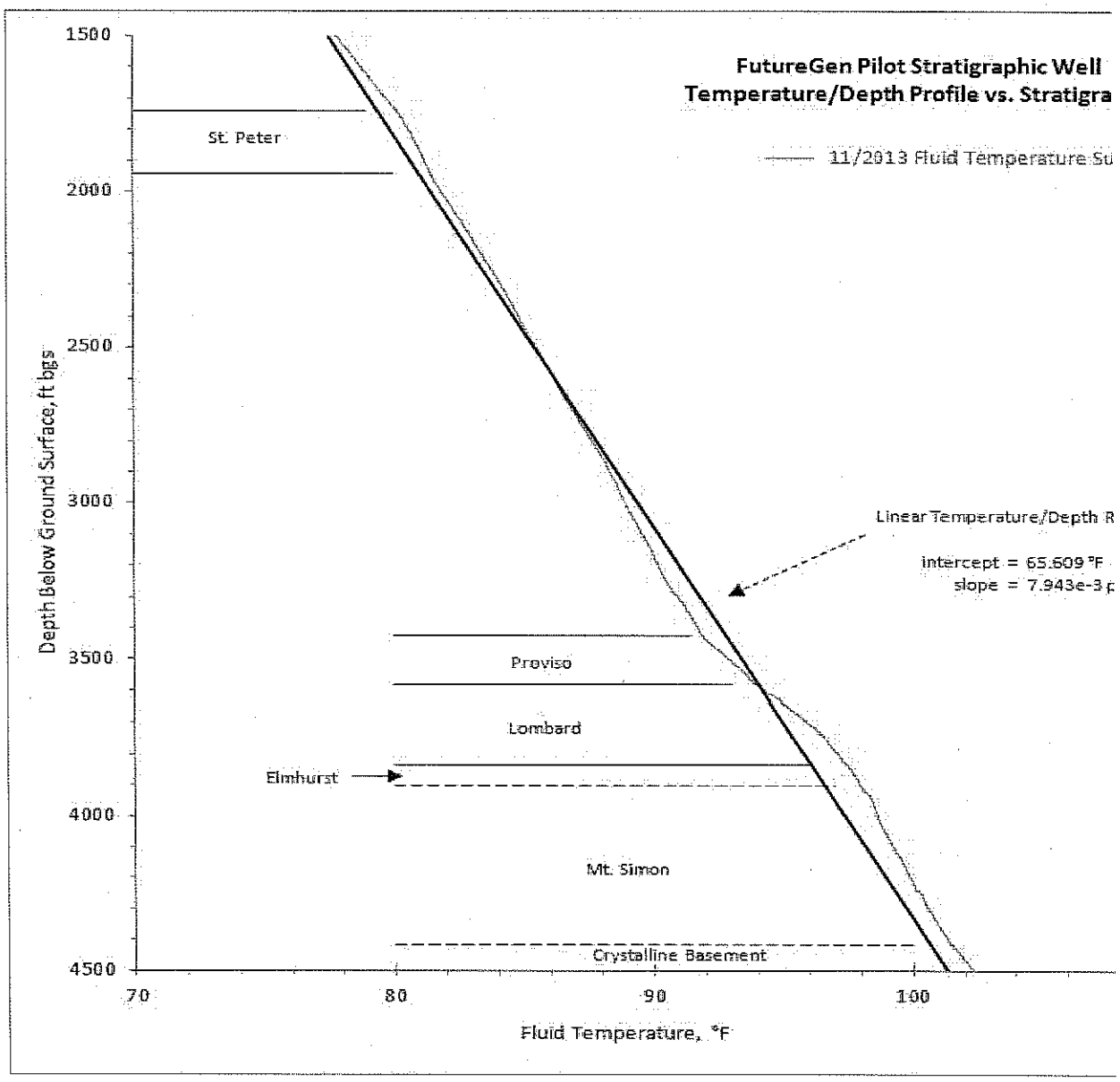

Test: 4,186 - 4,389 ft
4500
0
500
1000
1500
2000
Static Fluid Pressure, psi (gage)


FutureGen Pilot Well
Static Fluid Pressure vs. Depth Measurements in Relation to
Freshwater and Composite Formation Pressure Gradients
Mt. Simon MDT Tests (5)
St. Peter MDT Tests (4)
Silurian Limestone MDT Tests (2)
Freshwater Hydrostatic Pressure Gradient
Composite Formation Pressure Gradient
freshwater hydrostatic pressure gradient: 0.4331 psi/ft
Composite formation pressure/depth regression:
Intercept = -90.4630 psi
Slope = 0.46182 psi/ft
anticipated Potosi pressure/depth range
Supercritical CO2 Pressure: 1070 psi
Depth, ft bgs
500
1000
1500
2000
2500
3000
3500
4000
4500
0
500
1000
1500
2000
Static Fluid Pressure, psi (gage)


FutureGen Pilot Well
Mt. Simon Static Fluid Pressure vs. Depth Measurements
Pressure vs. Depth Regression
Upper Mt. Simon Packer Test: 3,934 - 4,180 ft
Mount Simon MDT Static Pressure Tests (5)
Freshwater Hydrostatic Pressure Gradient
Mt. Simon Pressure/Depth Regression
Mt. Simon pressure/depth regression:
Intercept = -88.4401 psi
Slope = 0.46167 psi/ft
GM13
GM12
GM118
freshwater hydrostatic pressure gradient: 0.4331 psi/ft
Lower Mt. Simon Packer Test: 4,186 - 4,389 ft
Depth, ft bgs
3800
3900
4000
4100
4200
4300
1700
1750
1800
1850
1900
Static Fluid Pressure, psi (gage)


FutureGen Pilot Well
Calculated Pressure Gradient
Mt. Simon MDT Tests (5)
Mt. Simon Packer Tests (2)
Mt. Simon Geomechanical Tests (3)
St. Peter MDT Tests (4)
Silurian Limestone MDT Tests (2)
Freshwater Hydrostric Gradient
Silurian Limestone measurements
St. Peter measurements
Freshwater hydrostatic gradient: 0.4331 psi/ft
Mt. Simon measurements
Depth, ft bgs
0
500
1000
1500
2000
2500
3000
3500
4000


4500
0.35
0.40
0.45
0.50
0.55
Pressure Gradient, psi/ft


FutureGen Pilot Stratigraphic Well
Temperature/Depth Profile vs. Stratigra
11/2013 Fluid Temperature Su
Linear Temperature/Depth R
intercept = 65.609 °F
slope = 7.943e-3 p
St. Peter
Proviso
Lombard
Elmhurst
Mt. Simon
Crystalline Basement
Depth Below Ground Surface, ft bgs
1500
2000
2500
3000
3500
4000
4500
70
80
90
100
Fluid Temperature, °F

EPA Pressure Front Calculation (Eqn. 1); @ existing conditions			
Top of Mt. Simon as basis	$P_{i,f}$	11.62	Mpa
	$P_{i,f}$	1685.12	psi
	z_u-z_i	1962.00	ft
Top of Elmhurst as basis	$P_{i,f}$	11.41	Mpa
	$P_{i,f}$	1655.56	psi
	z_u-z_i	1896.00	ft
	P_u	806.39	psi
(St. Peter to Mt. Simon)	Υ_w	64.4943	lb/ft^3

EPA Critical Pressure Change Calculation (Eqn. 2); @ existing conditions			
Top of Mt. Simon as basis	$\Delta P_{i,f}$	-0.19	Mpa
	$\Delta P_{i,f}$	-27.35	psi
	P_i	1712.47	psi
	z_u-z_i	1962.00	ft
Top of Elmhurst as basis	$\Delta P_{i,f}$	-0.18	Mpa
	$\Delta P_{i,f}$	-26.43	psi
	P_i	1681.99	psi
	z_u-z_i	1896.00	ft
	P_u	806.39	psi
	Υ_w	64.4943	lb/ft^3

EPA Pressure Front Calculation (Eqn. 1); for hydrostatic St. Peter conditions			
Top of Mt. Simon as basis	$P_{i,f}$	11.86	Mpa
	$P_{i,f}$	1719.82	psi
	z_u-z_i	1962.00	ft
Top of Elmhurst as basis	$P_{i,f}$	11.65	Mpa
	$P_{i,f}$	1690.26	psi
	z_u-z_i	1896.00	ft
	P_u	841.08	psi
	Υ_w	64.4943	lb/ft^3

EPA Critical Pressure Change Calculation (Eqn. 2); for hydrostatic St. Peter conditions			
Top of Mt. Simon as basis	$\Delta P_{i,f}$	0.05	Mpa
	$\Delta P_{i,f}$	7.35	psi
	P_i	1712.47	psi
	z_u-z_i	1962.00	ft
Top of Elmhurst as basis	$\Delta P_{i,f}$	0.06	Mpa
	$\Delta P_{i,f}$	8.27	psi
	P_i	1681.99	psi

$z_u - z_l$	1896.00	ft
P_u	841.08	psi
Υ_w	64.4943	lb/ft^3

Note 1: Projected static pressure for the various units based on regression relationships shown i

Projected Pressure at base of St. Peter	806.39	psig	see Note 1
Projected Pressure at top of Elmhurst	1681.99	psig	see Note 1
Projected Pressure at top of Mt. Simon	1712.47	psig	see Note 1
Depth to base of St. Peter	1942	ft bgs	
Depth to top of Elmhurst	3838	ft bgs	
Depth to top of Mt. Simon	3904	ft bgs	
Ground Surface Elevation	619	ft bgs	
Base of St. Peter Elevation	-1323	ft MSL	
Top of Elmhurst Elevation	-3219	ft MSL	
Top of Mt. Simon Elevation	-3285	ft MSL	
Calculated Specific Wt. of Mt. Simon water	64.4943	lb/ft3	Υ_w
Calculated Fluid Density of Mt. Simon	1.0331	g/cm3	ρ_w
freshwater hydrostatic gradient	0.4331	psi/ft	
Freshwater hydrostatic pressure: St. Peter	841.08	psi	

n "Mt. Simon Press-Regression" subfolder, for test data listed in "Combined Pressure Depth Data" subf

Birkholzer (2011) & EPA Pressure Front Calculation (Eqn. 1), @ existing conditions

Top of Mt. Simon as basis $P_{i,f}$

$P_{i,f}$

$z_u - z_i$

Top of Elmhurst as basis $P_{i,f}$

$P_{i,f}$

$z_u - z_i$

P_u

(St. Peter to Mt. Simon) γ_w

Birkholzer (2011) & EPA Critical Pressure Change Calculation (Eqn. 2), @ existing conditions

Top of Mt. Simon as basis $\Delta P_{i,f}$

$\Delta P_{i,f}$

P_i

$z_u - z_i$

Top of Elmhurst as basis $\Delta P_{i,f}$

$\Delta P_{i,f}$

P_i

$z_u - z_i$

P_u

(St. Peter to Mt. Simon) γ_w

Birkholzer (2011 & EPA Pressure Front Calculation (Eqn. 1), for hydrostatic St. Peter conditions

Top of Mt. Simon as basis $P_{i,f}$

$P_{i,f}$

$z_u - z_i$

Top of Elmhurst as basis $P_{i,f}$

$P_{i,f}$

$z_u - z_i$

P_u

(St. Peter to Mt. Simon) γ_w

Birkholzer (2011 & EPA Critical Pressure Change Calculation (Eqn. 2); for hydrostatic St. Peter condition

Top of Mt. Simon as basis $\Delta P_{i,f}$

$\Delta P_{i,f}$

P_i

$z_u - z_i$

Top of Elmhurst as basis $\Delta P_{i,f}$

$\Delta P_{i,f}$

P_i

$z_u - z_i$

P_u

(St. Peter to Mt. Simon) Υ_w

folder

11.63 Mpa
1686.55 psi
1962.00 ft
11.42 Mpa
1656.95 psi
1896.00 ft

806.39 psi 64.7523

64.5996 lb/ft^3 calculated based on HEADCO

-0.18 Mpa
-25.91 psi
1712.47 psi
1962.00 ft
-0.17 Mpa
-25.04 psi
1681.99 psi
1896.00 ft

806.39 psi

64.5996 lb/ft^3 calculated based on HEADCO

11.87 Mpa
1721.25 psi
1962.00 ft
11.66 Mpa
1691.64 psi
1896.00 ft

841.08 psi

64.5996 lb/ft^3 calculated based on HEADCO

s
0.06 Mpa
8.78 psi
1712.47 psi
1962.00 ft
0.07 Mpa
9.65 psi
1681.99 psi

1896.00	ft	
841.08	psi	
64.5996	lb/ft^3	calculated based on HEADCO

Dynamic Viscosity Calculation for Temperature/Pressure/Salinity Conditions in centipoise (cp)

Ref: Meehan, D.N. 1980. "Estimating Water Viscosity at Reservoir Conditions", Petroleum Engineer, July 19

μ^* (dynamic viscosity, cp) = (A+B/T)*f(p,T)

A = -0.04518+0.009313(%NaCl)-0.000393 (%NaCl)2

B = 70.634 + 0.09576(%NaCl)2

f(p,T) = 1 + 3.5x10-12(P)2(T-40)

Density calculate
30K ppm
47K ppm
60K ppm

Temp. F	P, psi	Salinity %
97.99	1712.47	4.7

A	-0.01009
B	72.74934
f(p,T)	1.00060

μ, cp	0.73233	temp+salinity co	1 darcy	1.06240E-11
μ, cp	0.73276	& P corrected	1 cp	2.088543E-05
μ_{fw},	1.5304E-05	lb-sec/ft^2	ρ_{stp}	0.999014
Res. Fluid Density ρ_{fw}	1.0331	g/cm^3	γ_{std}	62.3664
Res. Specific Fluid Wt. γ_{fw}	64.4943	lb/ft^3	μ_{stp},	2.3590E-05
			μ_{stp},	1.1295

STP k→K equivalents			
k	1000	mD	*STP conditions
K	2.427	ft/day	*STP conditions
1 ft/day (K) = k (mD)	412.074	mD	*STP conditions

Res. Conditions k→K equivalents			
k	1000	millidarcies	*Res. conditions
K	3.868	ft/day	*Res. conditions
1 ft/day (K) = k (mD)	258.513	mD	*Res. conditions

Notes:

1. P estimated from projected static pressure for the top of the Mt. Simon based on regression relationships

2. ρ_{fw} saline water density calculator http://www.csgnetwork.com/water_density_calculator.html for Temp., P,

3. Salinity value (tds = 47,000 ppm) based on average MDT and composite Mt. Simon formation fluid sample

)80, pp. 117-118.

d values based on Temp. and Salinity (no pressure effects)	http://www.csgnetwork.com/h2o
1.01562	
1.02828	
1.03805	

ft^2
$lb\text{-}sec/ft^2$
g/cm^3
lb/ft^3
$lb\text{-}sec/ft^2$
cp

shown in "Mt. Simon Press-Regression" subfolder, for test data listed in "Combined Pressure Depth Data

and Salinity conditions shown in row 9

es as reported in Kelley et al. (2012)

denscalc.html

" subfolder