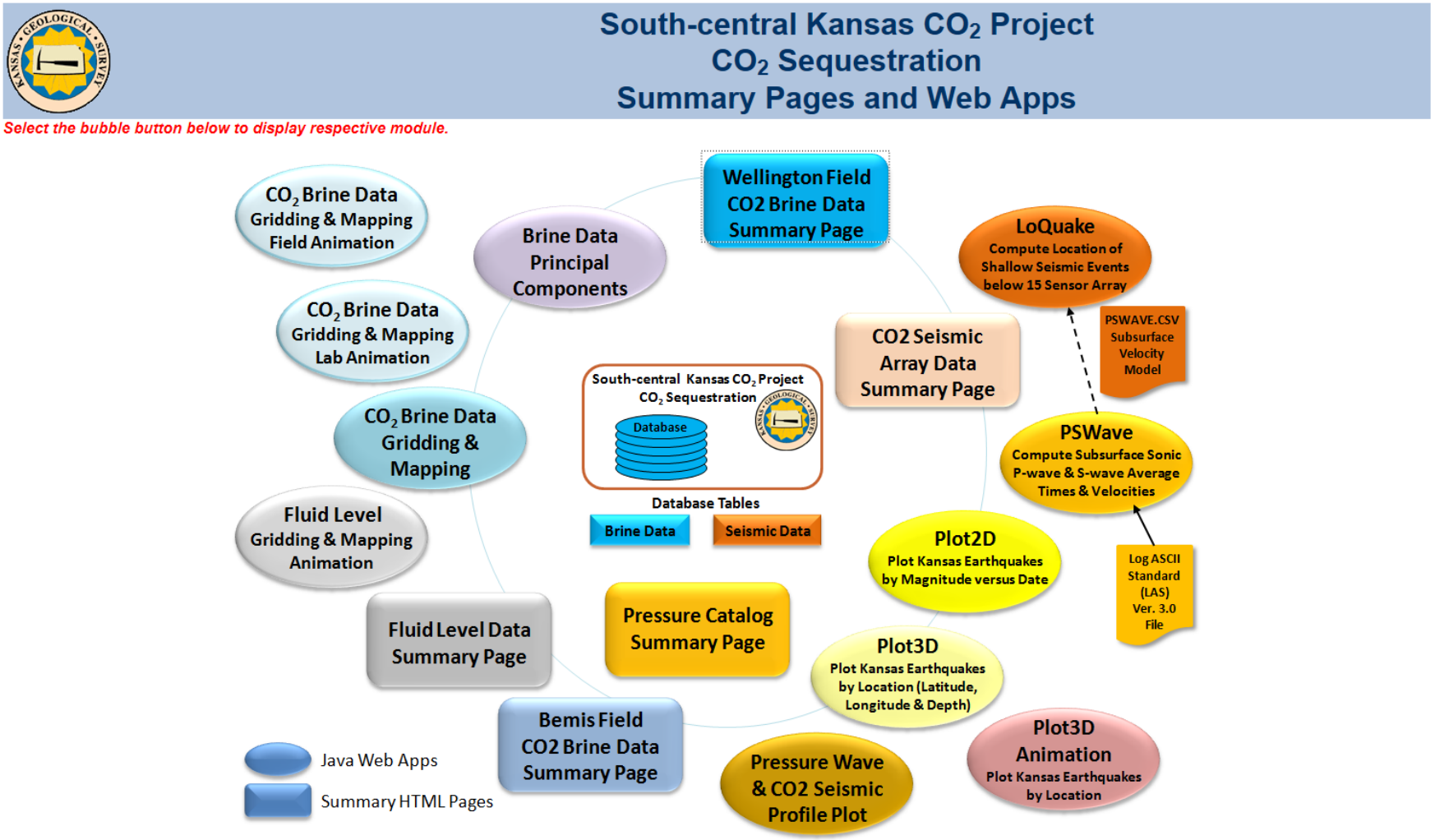
Interactive Database for Wellington CO_2 EOR and Storage Project

John Victorine, Eugene Holubnyak, Lynn Watney, and Jennifer Hollenbach



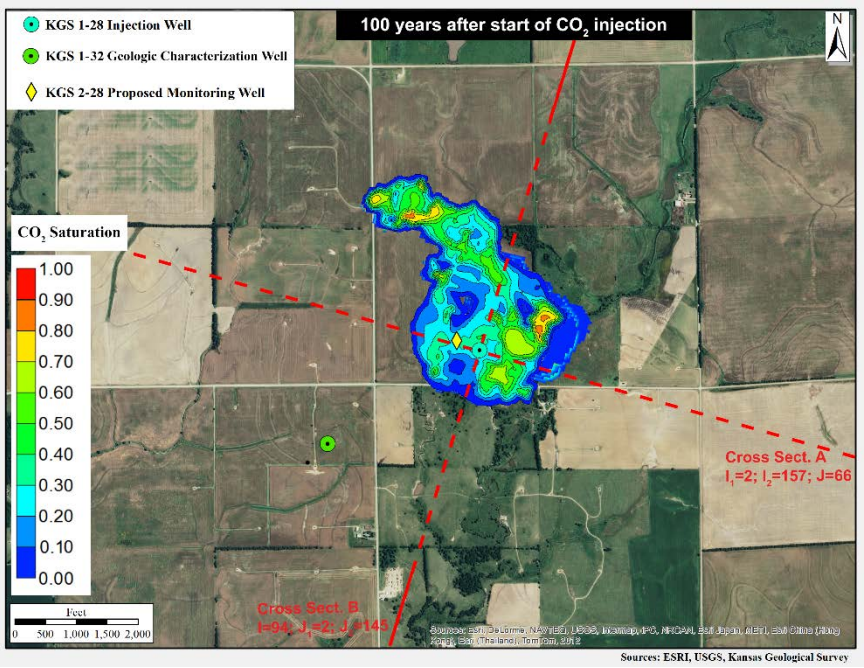
Data Types

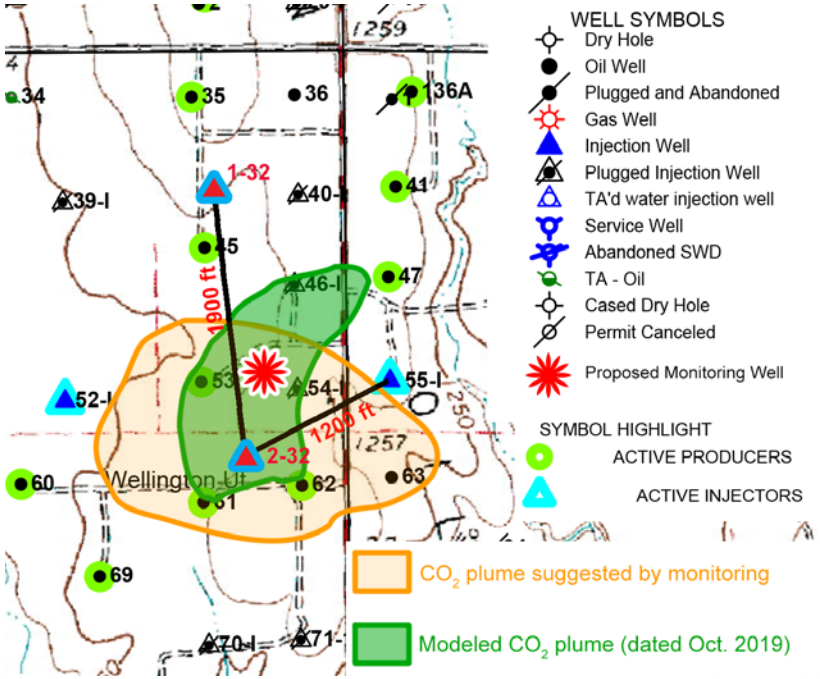
CO_2-EOR performance monitoring

- Geochemical survey
- Oilfield production history

Seismic array

Deep saline aquifer continuous pressure monitoring





Gridding & Mapping Applets – Animation – Colorlith Brine Data & Fluid Level Data Sets

This gridding and mapping module allows the user to plot the brine data for the CO_2 Project Wells Map. The map displays a colorlith presentation of the brine data, i.e. 3 brine data curves mapped to 3 colors Red, Green and Blue respectively and mixes the color to reflect the general chemistry. The idea is that by picking and plotting the right three curves that may be especially sensitive to the brine chemistry and reflect the CO_2 interaction and see a change in the presentation on the map by the color change.

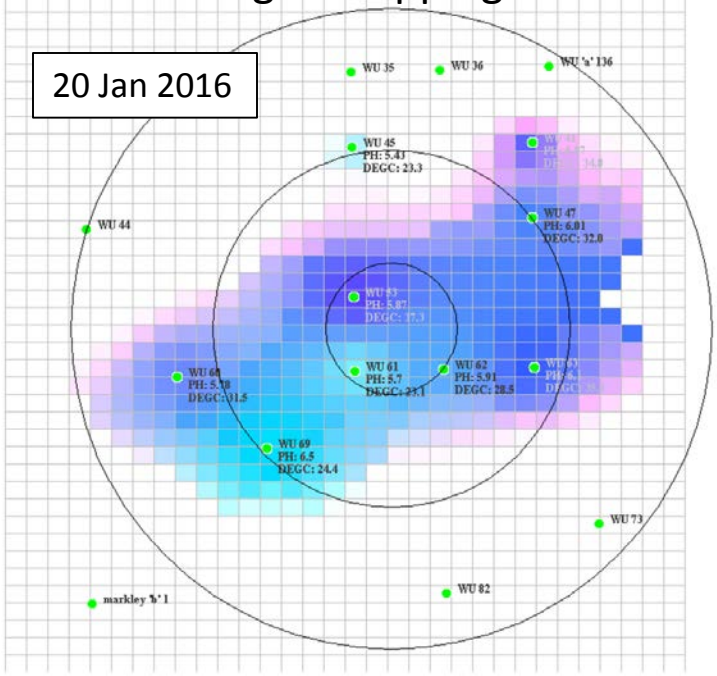
Gridding & Mapping
The interpolation algorithm is a simple inverse distance weighted averaging. The effects of varying the exponent are described in Davis (1986). A simple nearest neighbor search is employed.

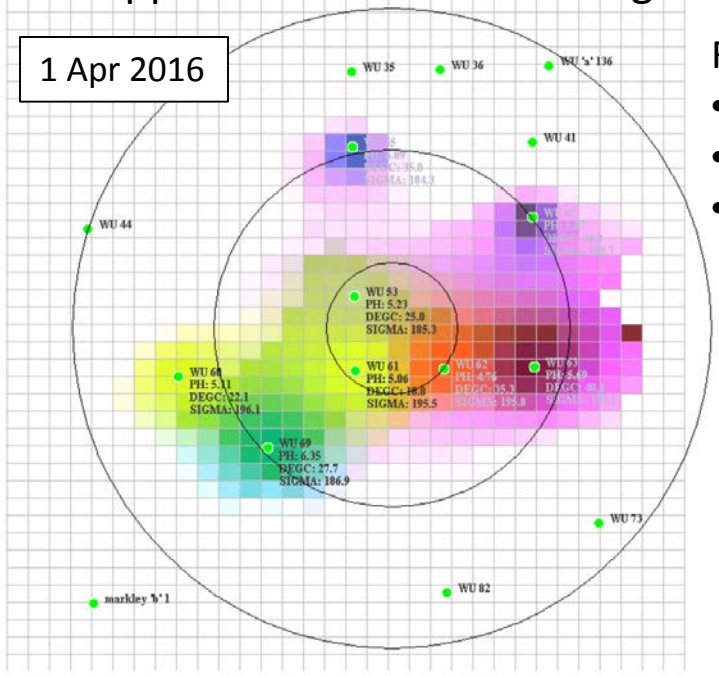
Davis, J.C., 1986, Statistics and Data Analysis in Geology, Second Edition, John Wiley & Sons, New York, 646 pp.

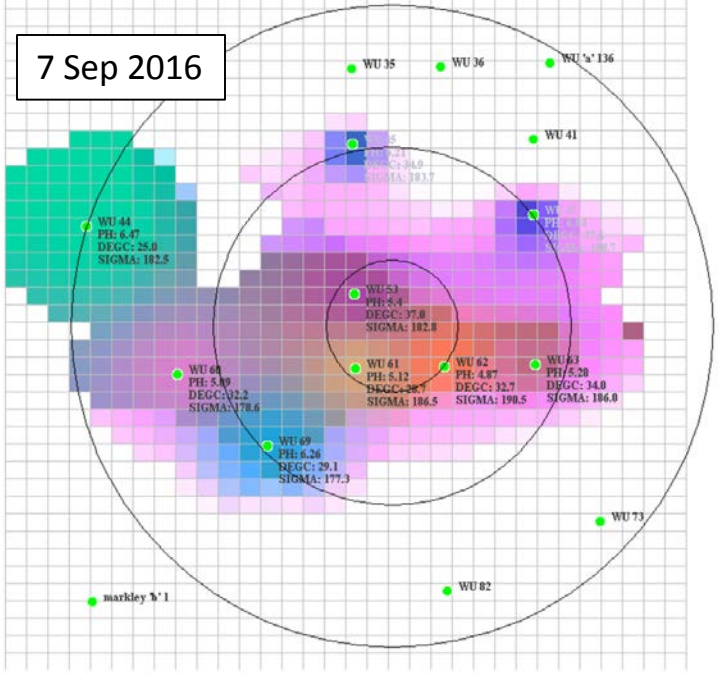
Peter L. Briggs identified a method to assist geologist in well log interpretation by creating a color log presentation.
Peter L. Briggs, Mathematical Geology, Volume 17, Number 4, May 1985

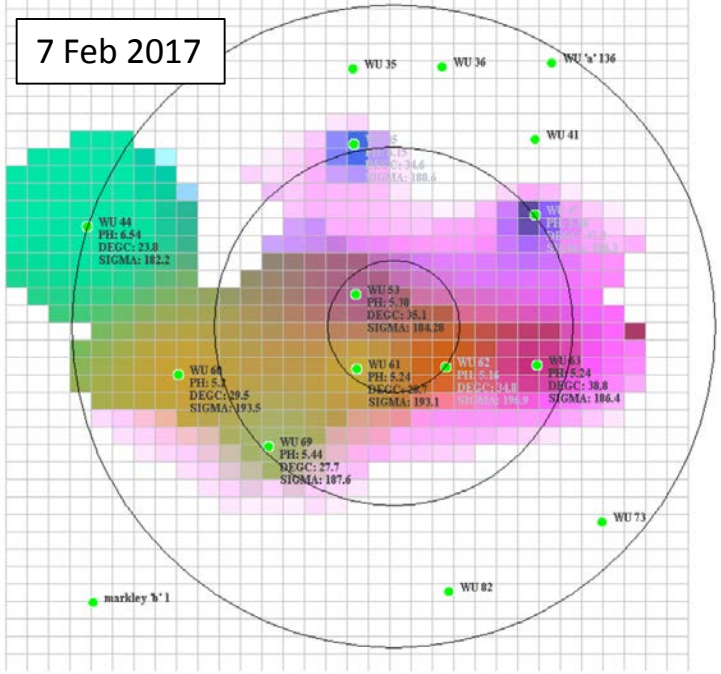
David R. Collins & John H. Doveton extended this technique to identify lithology by using the neutron & density porosity and gamma ray logs, by noting that several porosity log readings gave direct indications of the rock mineralogy.
Color Images of Kansas Subsurface Geology from Well Logs, D. R. Collins and J. H. Doveton, Computer & Geosciences, Vol. 12, No. 4B, pp.519-526 1986

JAVA Gridding & Mapping Animation Web Applet – Nearest Monitoring Wells



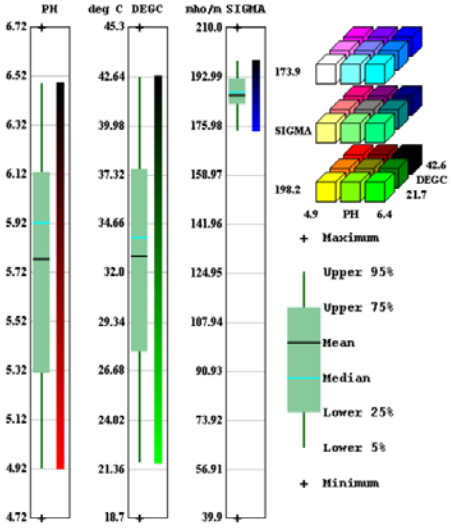






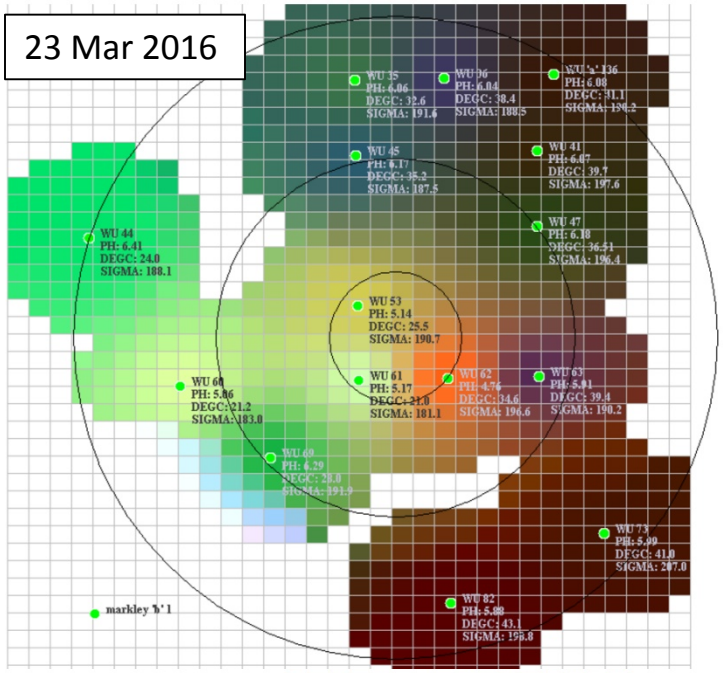
Field Test Data

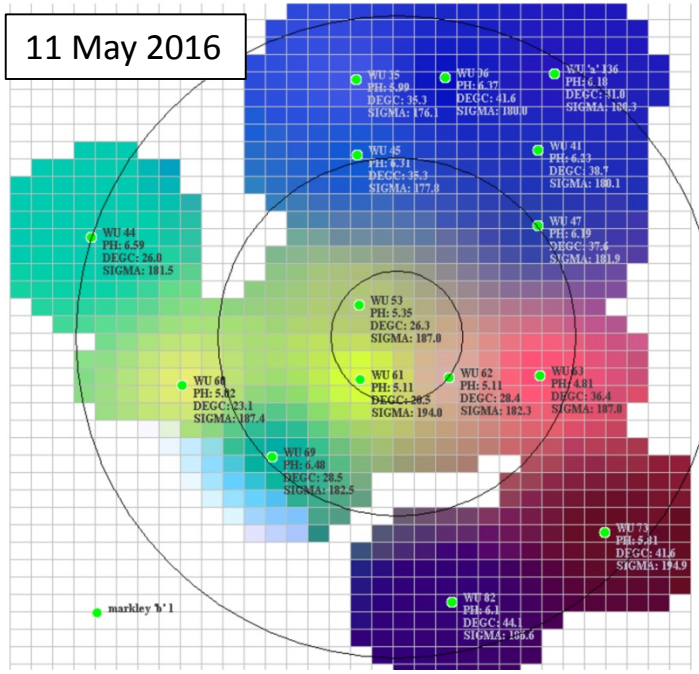
- PH
- Temperature [deg C]
- Conductivity [mho/m]

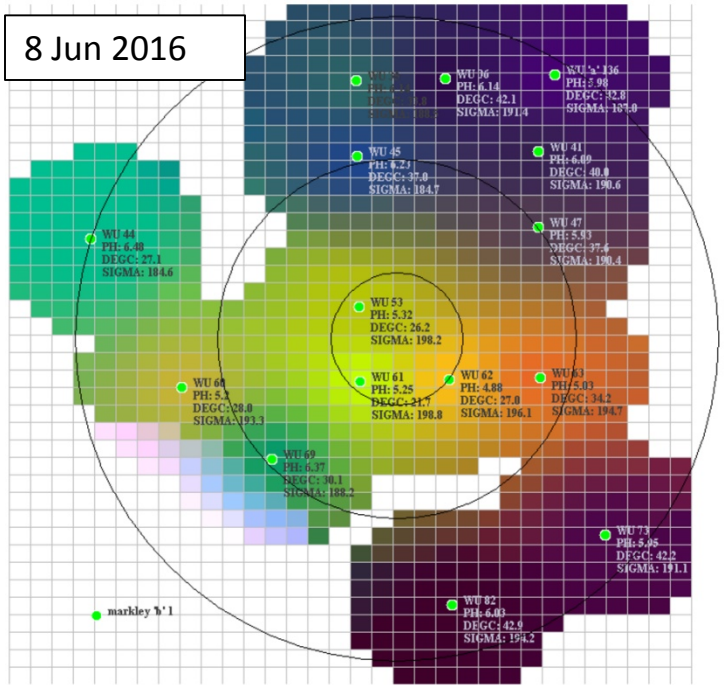


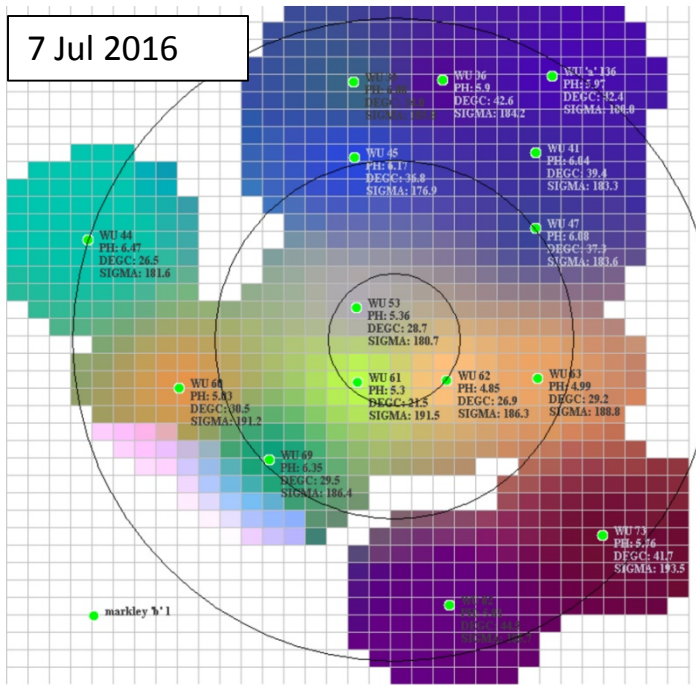
CO_2 Brine Data
Gridding & Mapping
Field Animation

JAVA Gridding & Mapping Animation Web Applet – All Monitoring Wells



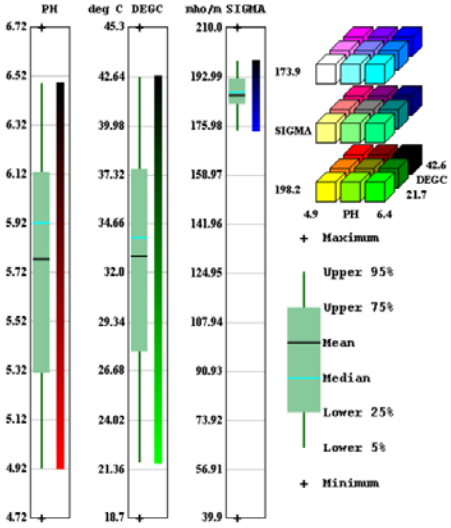






Field Test Data

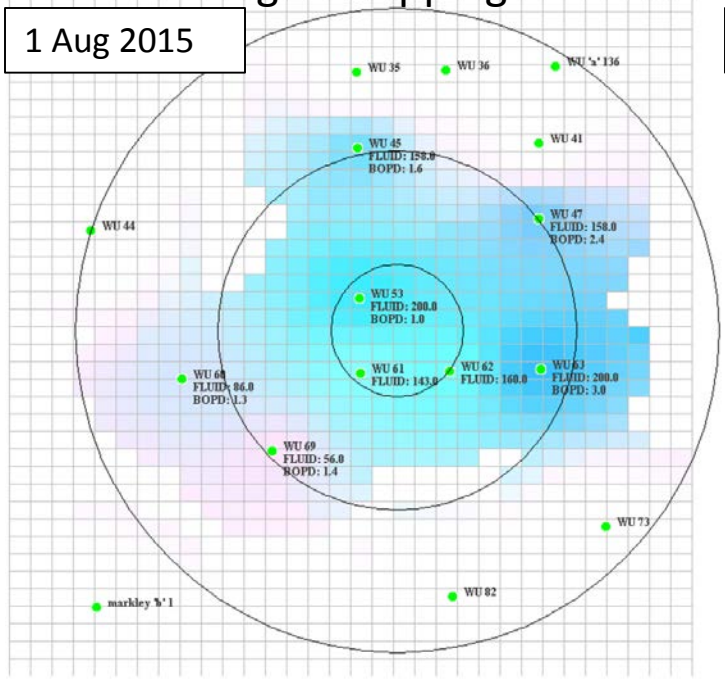
- PH
- Temperature [deg C]
- Conductivity [mho/m]



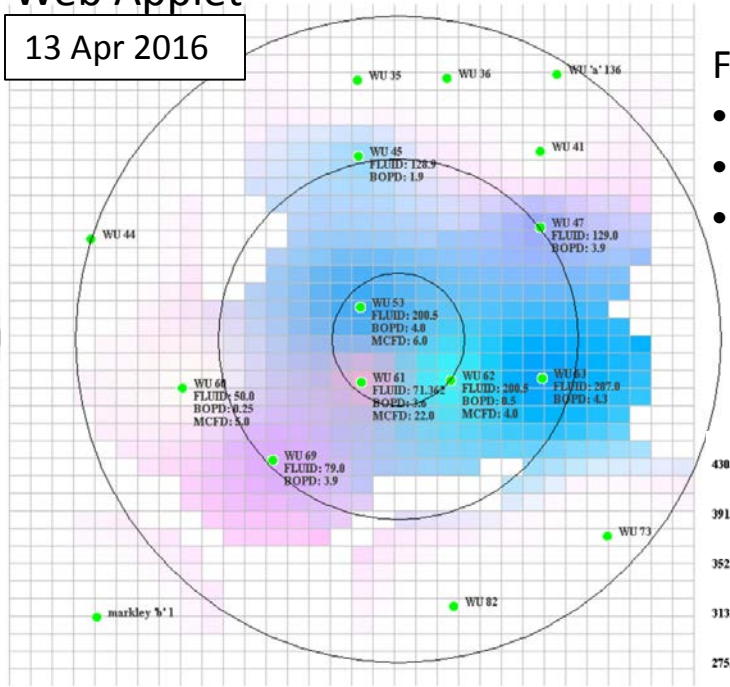
CO_2 Brine Data Gridding & Mapping Field Animation

JAVA Gridding & Mapping Animation Web Applet

1 Aug 2015

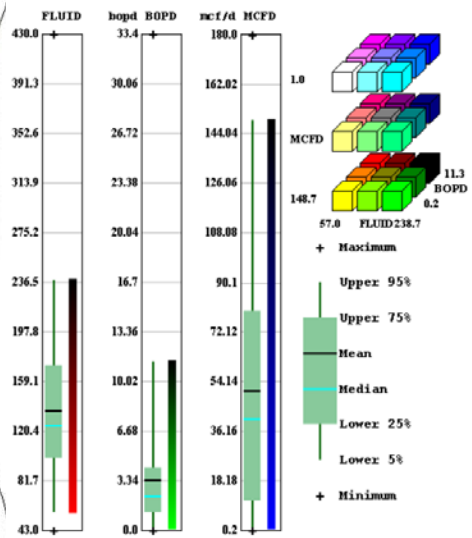


13 Apr 2016

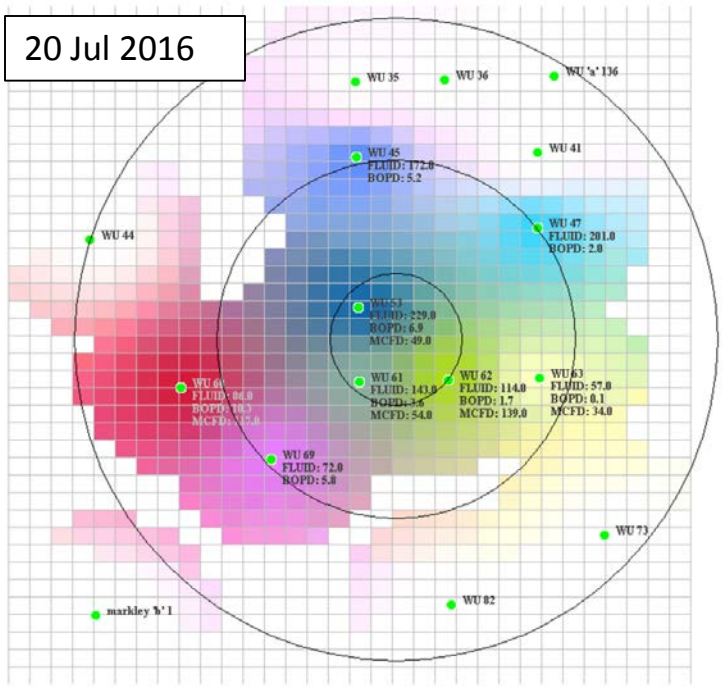


Fluid Data

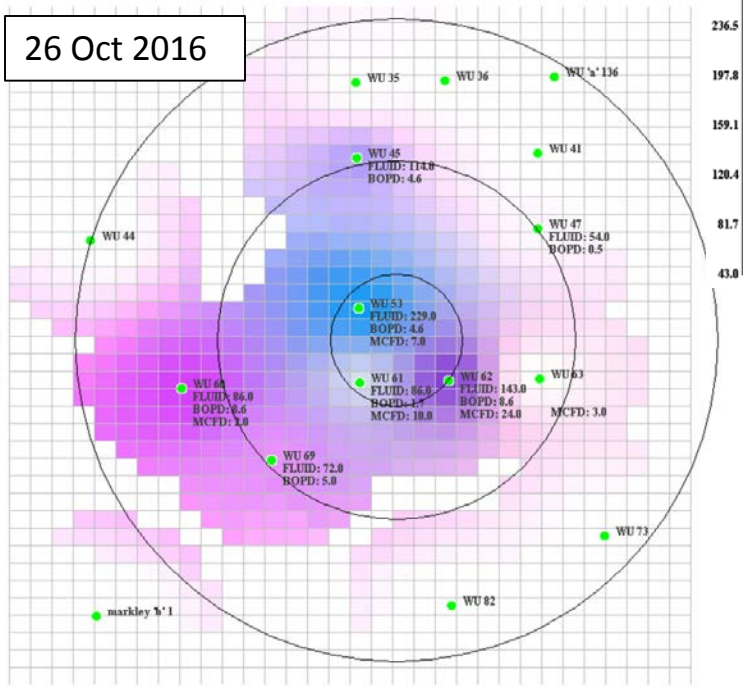
- Total Fluid [bbl]
- Barrels of Oil per day
- CO_2 Emission [mcfd]



20 Jul 2016



26 Oct 2016



Fluid Level Gridding & Mapping Animation

Principal Components Analysis

"*Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors are an uncorrelated orthogonal basis set. The principal components are orthogonal because they are the eigenvectors of the covariance matrix, which is symmetric. PCA is sensitive to the relative scaling of the original variables.*"
Wikipedia, the free encyclopedia
(https://en.wikipedia.org/wiki/Principal_component_analysis)

References

A tutorial on Principal Components Analysis by Linsay I Smith February 26, 2002

Brine Data Principal Components

The brine data is first converted from mg/l to meq/l.

Sigma * -3.0 -2.5 -2.4 -2.3 -2.2 -2.1 -2.0 -1.9 -1.8 -1.7 -1.6 -1.5

1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 3.0

	API-Number	Na	K	Mg	Ca	Ba	MnII	FeIII	Cl	Br	SO4	PH
i = 1	15-191-10045	2414.09	11.2	204.11	573.85	0.0	0.03	0.71	3497.88	5.88	14.03	5.74
2	15-191-10054	2422.79	10.2	187.65	578.84	0.0	0.03	0.57	3526.09	5.63	13.13	5.94
3	15-191-10055	2757.72	9.3	276.54	533.93	0.21	0.02	0.76	4090.26	8.13	6.97	5.83
	15-191-10078	2496.73	11.89	213.99	578.84	0.0	0.04	1.42	3300.42	5.88	14.4	5.98
	15-191-10076	2701.17	9.97	200.0	608.78	0.0	0.03	1.18	3497.88	5.75	13.47	5.88
	15-191-10087	2561.98	12.22	198.35	578.84	0.01	0.03	1.29	3526.09	5.63	13.2	5.87
.	15-191-10136	2418.44	10.79	193.41	558.88	0.0	0.03	0.59	3582.51	6.0	13.17	5.8
.	15-191-10134	2453.24	11.09	195.06	573.85	0.01	0.02	0.89	3554.3	5.88	13.47	5.81
.	15-191-10083	2322.74	12.22	187.65	538.92	0.0	0.02	0.93	3300.42	4.88	14.19	6.31
	15-191-43882	2648.97	9.71	239.5	633.73	0.0	0.02	0.75	3723.55	6.88	11.86	5.75
	15-191-11442	2435.84	10.99	195.06	588.82	0.0	0.02	0.81	3526.09	6.0	13.51	5.73
	15-191-22770	1726.83	6.9	137.44	406.18	0.01	0.04	1.18	2397.74	4.38	15.84	6.86
	15-191-22770	2409.74	9.71	227.16	638.72	0.0	0.17	5.8	3723.55	6.13	15.15	5.25
N	15-191-22770	2105.26	7.92	163.78	495.0	0.01	0.04	0.0	3074.75	5.25	15.11	7.05

	Na	K	Mg	Ca	Ba	MnII	FeIII	Cl	Br	SO4	PH
Mean	2,419.681	10.294	201.407	563.37	0.018	0.039	1.206	3,451.538	5.879	13.393	5.986
Sigma	257.517	1.546	32.778	58.928	0.055	0.039	1.37	382.579	0.875	2.11	0.467

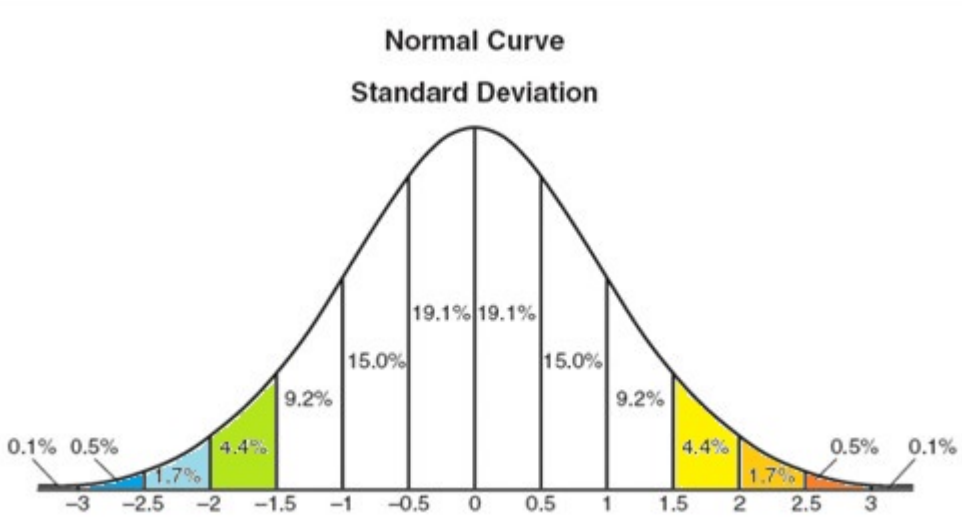
k = 1 2 3 . . . M

Mean $\bar{X}_k$ is the average value of each column k

$$\bar{X}_k = \frac{\sum_{i=1}^{N} X_i}{N}$$

Sigma (Standard Deviation) σ_k is a measure of how spread out the k^{th} data column is.

$$\sigma_k = \left[\frac{\sum_{i=1}^{N} (X_{ik} - \bar{X}_k)^2}{(N-1)} \right]^{1/2}$$



The brine data cells are colored to illustrate how spread out the data is with respect to the standard deviation, i.e. green and blues from -1.5σ to less than -3σ and yellows and oranges from 1.5σ to above 3σ.

	Na	K	Mg	Ca	Ba	MnII	FeIII	Cl	Br	SO4	PH
i = 1	2414.09	11.2	204.11	573.85	0.0	0.03	0.71	3497.88	5.88	14.03	5.74
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	2496.73	11.89	213.99	578.84	0.0	0.04	1.42	3300.42	5.88	14.4	5.98
	2701.17	9.97	200.0	608.78	0.0	0.03	1.18	3497.88	5.75	13.47	5.88
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	2409.74	9.71	227.16	638.72	0.0	0.17	5.8	3723.55	6.13	15.15	5.25
N	2105.26	7.92	163.78	495.0	0.01	0.04	0.0	3074.75	5.25	15.11	7.05
	k = 1	2	3			. . .					M

Normalize each column to its standard deviation. Unless the data is normalized, a variable with a large variance will dominate.

$x_{ik} = X_{ik} / \sigma_k$, **where i is the row, k is column**

Covariance Matrix

	Na	K	Mg	Ca	Ba	MnII	FeIII	Cl	Br	SO4	PH
Na	0.999	0.537	0.83	0.786	0.337	-0.122	0.028	0.902	0.768	-0.676	-0.719
K	0.537	1.0	0.262	0.56	-0.214	-0.182	-0.009	0.435	0.08	-0.064	-0.529
Mg	0.83	0.262	0.999	0.6	0.62	0.112	0.235	0.881	0.938	-0.788	-0.679
Ca	0.786	0.56	0.6	1.0	-0.192	0.267	0.379	0.753	0.47	-0.175	-0.846
Ba	0.337	-0.214	0.62	-0.192	1.0	-0.148	-0.109	0.44	0.711	-0.859	-0.048
MnII	-0.122	-0.182	0.112	0.267	-0.148	1.0	0.948	0.067	-0.022	0.346	-0.335
FeIII	0.028	-0.009	0.235	0.379	-0.109	0.948	0.999	0.164	0.05	0.25	-0.502
Cl	0.902	0.435	0.881	0.753	0.44	0.067	0.164	1.0	0.857	-0.719	-0.784
Br	0.768	0.08	0.938	0.47	0.711	-0.022	0.05	0.857	0.999	-0.875	-0.578
SO4	-0.676	-0.064	-0.788	-0.175	-0.859	0.346	0.25	-0.719	-0.875	1.0	0.324
PH	-0.719	-0.529	-0.679	-0.846	-0.048	-0.335	-0.502	-0.784	-0.578	0.324	1.0

y ↓

X →

Covariance cov(x,y) is a measure how much each data column vary from the mean with respect to each other.

$$\mathrm{cov}(x,y) = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y})}{(N-1)}$$

where x is the mean of brine data column k divided by σ_k

x_i is the individual brine data divided by σ_k; i= well

e.g. cov (Na, Ca) is sum over the Na and Ca columns of the normalized data set.

Covariance Matrix

$$C = \begin{bmatrix} \mathrm{cov}(Na, Na) & \mathrm{cov}(Na, K) & \mathrm{cov}(Na, Mg) & \dots & \mathrm{cov}(Na, SO_4) & \mathrm{cov}(Na, PH) \\ \mathrm{cov}(K, Na) & \mathrm{cov}(K, K) & \mathrm{cov}(K, Mg) & \dots & \mathrm{cov}(K, SO_4) & \mathrm{cov}(K, PH) \\ \mathrm{cov}(Mg, Na) & \mathrm{cov}(Mg, K) & \mathrm{cov}(Mg, Mg) & \dots & \mathrm{cov}(Mg, SO_4) & \mathrm{cov}(Mg, PH) \\ & & \vdots & & & \vdots \\ \mathrm{cov}(SO_4, Na) & \mathrm{cov}(SO_4, K) & \mathrm{cov}(SO_4, Mg) & \dots & \mathrm{cov}(SO_4, SO_4) & \mathrm{cov}(SO_4, PH) \\ \mathrm{cov}(PH, Na) & \mathrm{cov}(PH, K) & \mathrm{cov}(PH, Mg) & \dots & \mathrm{cov}(PH, SO_4) & \mathrm{cov}(PH, PH) \end{bmatrix}$$

To compute the Eigenvectors and Eigenvalues this web app uses JAMA a Java Matrix Package (http://math.nist.gov/javanumerics/jama/).

"JAMA is a basic linear algebra package for Java. It provides user-level classes for constructing and manipulating real, dense matrices. It is meant to provide sufficient functionality for routine problems, packaged in a way that is natural and understandable to non-experts. It is intended to serve as the standard matrix class for Java."

JAMA Java Functions:
C - Covariance Matrix
Compute eigenvalues & eigenvectors JAMA function
E_v = C.eig(), where eig() function computes the eigenvalues & eigenvectors of the covariance matrix C.
Eigenvalues = E_v.getRealEigenvalues()
Eigenvectors = E_v.getV()

1st two principal component vectors: Pc_2 Pc_1

Eigenvectors →

	1	2	3	4	5	6	7	8	9	10	11
Na	-0.19	0.03	-0.309	0.404	0.59	0.007	-0.377	-0.143	-0.203	0.011	-0.386
K	0.131	-0.17	-0.066	0.039	-0.227	-0.03	-0.135	0.711	-0.558	-0.165	-0.175
Mg	-0.152	0.511	-0.029	-0.277	-0.249	-0.577	-0.242	0.04	0.146	0.045	-0.396
Ca	0.512	-0.089	0.478	-0.18	0.044	0.008	-0.198	-0.415	-0.229	-0.327	-0.305
Ba	0.243	0.151	0.507	0.295	0.178	0.152	-0.064	0.412	0.382	0.39	-0.21
MnII	0.378	0.166	-0.43	0.19	-0.214	0.265	-0.218	0.07	0.465	-0.47	-0.023
FeIII	-0.35	-0.418	0.194	-0.254	0.32	-0.15	-0.037	0.264	0.398	-0.487	-0.082
Cl	-0.47	0.1	0.118	-0.167	-0.295	0.684	-0.02	-0.069	-0.037	-0.016	-0.403
Br	-0.025	-0.578	-0.057	0.391	-0.439	-0.241	0.108	-0.202	0.182	0.167	-0.376
SO4	-0.33	0.231	0.412	0.57	-0.221	-0.127	-0.141	-0.072	-0.108	-0.37	0.318
PH	-0.052	-0.276	0.03	-0.173	-0.157	0.068	-0.809	-0.039	0.07	0.294	0.334

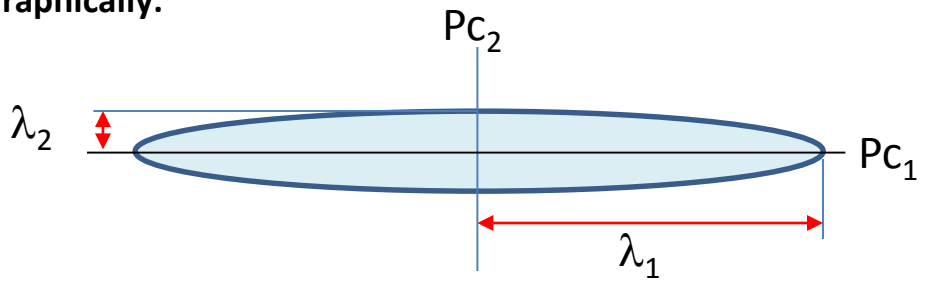
1st two principal component eigenvalues: λ_2 λ_1

Eigenvalues →

	1	2	3	4	5	6	7	8	9	10	11
Eigen	0.004	0.007	0.009	0.027	0.085	0.096	0.161	0.403	1.721	2.715	5.772
%	0	0	0	0.2	0.7	0.8	1.4	3.6	15.6	24.6	52.4

The principal components is less than or equal to the number of original variables. The first principal component Pc_1 has the largest possible variance i.e., it accounts for as much of the variability in the data as possible and the next principal component Pc_2 has the highest variance possible under the constraint that it is orthogonal to the preceding component. The principal components are orthogonal because they are the eigenvectors of the covariance matrix, which is symmetric.

Graphically:



Construct a Feature Vector from the 1st two principal components.

Feature Vector [V] =

Pc_1	Pc_2	
-0.386	0.011	Na
-0.175	-0.165	K
-0.396	0.045	Mg
-0.305	-0.327	Ca
-0.21	0.39	Ba
-0.023	-0.47	MnII
-0.082	-0.487	FeIII
-0.403	-0.016	Cl
-0.376	0.167	Br
0.318	-0.37	SO4
0.334	0.294	PH

Then construct an Adjusted Data Matrix from the Brine Data Matrix by subtracting the mean of each column and then dividing the standard deviation of the each column.

Adjusted Data Matrix [Am] = [$(X_{ik} - \overline{X}_k) / \sigma_k$]

where $\overline{X}_k$ is the mean of brine data column k

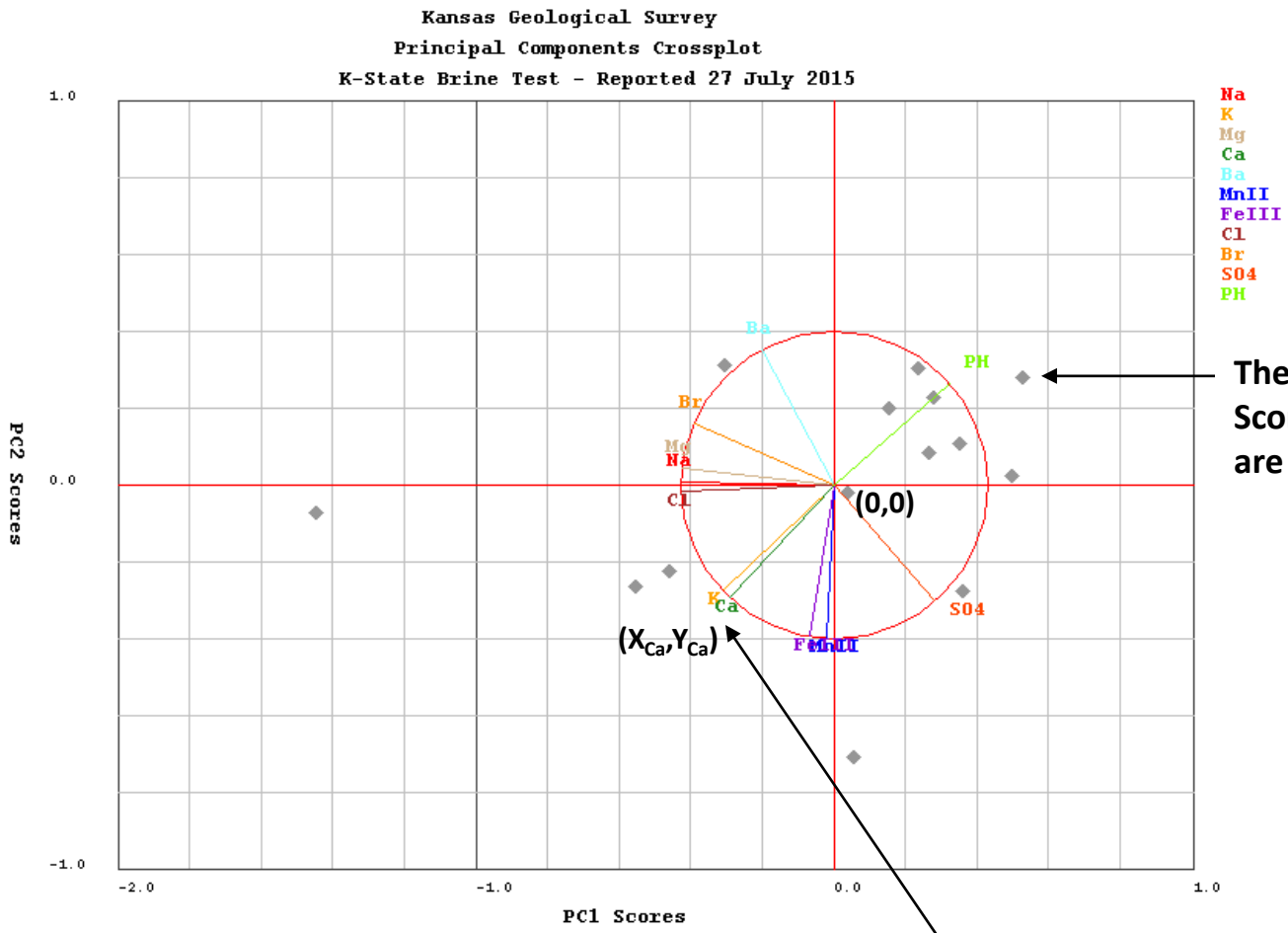
X_{ik} is the individual brine data; i=well, k=brine data

σ_{jk} is the standard deviation of the brine data column

Compute the Principal Components Scores [PC Scores] matrix as the Adjusted Data matrix times the Feature Vector.

[PC Scores] = [Am] X [V]

The [PC Scores] converts the multi dimensional matrix into a 2 dimensional matrix.



The Principal Component Scores Matrix [PC Scores] are gray diamonds.

The Feature Vector is represented as colored lines around a red unit circle, where each Feature Vector row is normalized to 1, i.e.

$X_k = Pc_{1k} / (Pc_{1k}^2 + Pc_{2k}^2)^{0.5}$
$Y_k = Pc_{2k} / (Pc_{1k}^2 + Pc_{2k}^2)^{0.5}$

where k is the analyte being computed.

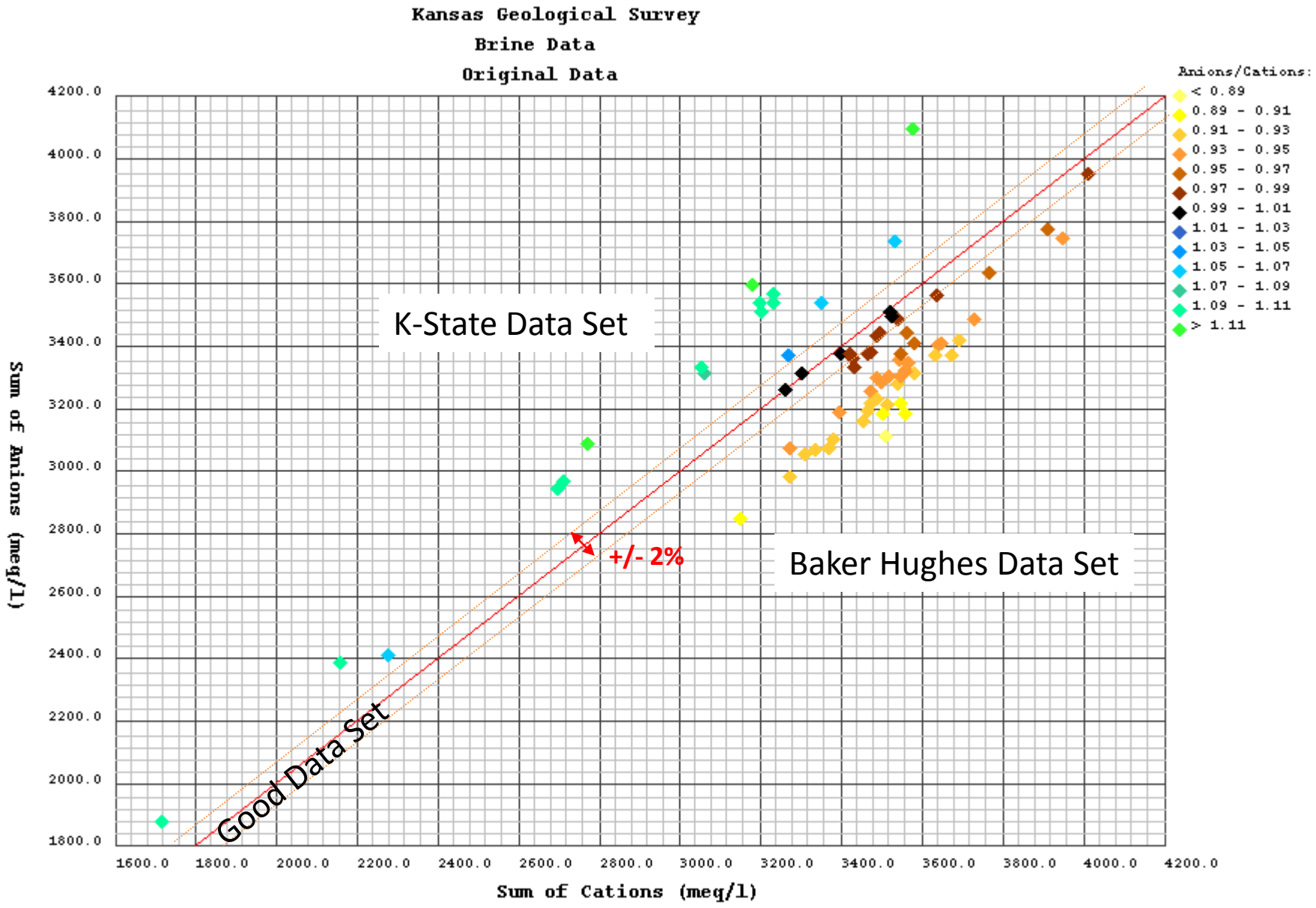
Feature Vector [V] =

Pc_1	Pc_2	
-0.386	0.011	Na
-0.175	-0.165	K
-0.396	0.045	Mg
-0.305	-0.327	Ca
-0.21	0.39	Ba
-0.023	-0.47	MnII
-0.082	-0.487	FeIII
-0.403	-0.016	Cl
-0.376	0.167	Br
0.318	-0.37	SO4
0.334	0.294	PH

Principal Components Analysis
Normalizing the Brine Data Set

If the eigenvector is used on the Adjusted Data Matrix and the Original Mean is added back then you would expect to get the original Brine data matrix back. So if you use the "Good" Data eigenvector as the measure of what the data should be then you would expect that the Brine Data set can be "corrected" to the "Good" data set.

- Define "Good" Data Set
  - Brine data falling between +/- 2% of the Anions/Cations Ratio
- Separate Brine Data to
  - Above 2% of the Good Data Set
  - Below 2% of the Good Data Set
- Construct an Eigenvector for the Good Data Set
  - Assuming that the data has a measurement "Error" to the Good Data Set.
  - Correct the Above and Below Data Sets by using the Eigenvector of the Good Data Set to "correct" the Brine Data to the define "Good" Data Set.


Kansas Geological Survey
Brine Data
Original Data
Anions/Cations:
< 0.89
0.89 - 0.91
0.91 - 0.93
0.93 - 0.95
0.95 - 0.97
0.97 - 0.99
0.99 - 1.01
1.01 - 1.03
1.03 - 1.05
1.05 - 1.07
1.07 - 1.09
1.09 - 1.11
> 1.11
K-State Data Set
Baker Hughes Data Set
+/- 2%
Good Data Set
Sum of Anions (meq/l)
Sum of Cations (meq/l)
4200.0
4000.0
3800.0
3600.0
3400.0
3200.0
3000.0
2800.0
2600.0
2400.0
2200.0
2000.0
1800.0
1600.0
1800.0
2000.0
2200.0
2400.0
2600.0
2800.0
3000.0
3200.0
3400.0
3600.0
3800.0
4000.0
4200.0

Covariance Matrix – Good Data Set

	Na	K	Mg	Ca	Sr	MnII	FeII	Cl	SO4	PH
Na	1.0	-0.672	0.88	0.218	0.754	-0.135	-0.033	0.988	-0.262	-0.327
K	-0.672	1.0	-0.457	-0.065	-0.831	0.253	0.048	-0.584	-0.224	0.216
Mg	0.88	-0.457	1.0	-0.049	0.761	0.001	0.09	0.921	-0.366	-0.208
Ca	0.218	-0.065	-0.049	0.999	0.01	0.093	-0.009	0.165	0.496	-0.729
Sr	0.754	-0.831	0.761	0.01	0.999	-0.077	0.11	0.713	0.128	-0.397
MnII	-0.135	0.253	0.001	0.093	-0.077	0.999	0.958	-0.11	0.186	-0.326
FeII	-0.033	0.048	0.09	-0.009	0.11	0.958	0.999	-0.023	0.191	-0.337
Cl	0.988	-0.584	0.921	0.165	0.713	-0.11	-0.023	1.0	-0.353	-0.265
SO4	-0.262	-0.224	-0.366	0.496	0.128	0.186	0.191	-0.353	1.0	-0.505
PH	-0.327	0.216	-0.208	-0.729	-0.397	-0.326	-0.337	-0.265	-0.505	0.999

y ↓

X →

Covariance cov(x,y) is a measure how much each data column vary from the mean with respect to each other.

$$\mathrm{cov}(x,y) = \frac{\sum_{i=1} (x_i - \bar{x})(y_i - \bar{y})}{(N-1)}$$

where x is the mean of brine data column k divided by σ_k

x_i is the individual brine data divided by σ_k; i= well

e.g. cov (Na, Ca) is sum over the Na and Ca columns of the normalized data set.

Covariance Matrix

$$C = \begin{bmatrix} \mathrm{cov}(Na, Na) & \mathrm{cov}(Na, K) & \mathrm{cov}(Na, Mg) & \dots & \mathrm{cov}(Na, SO_4) & \mathrm{cov}(Na, PH) \\ \mathrm{cov}(K, Na) & \mathrm{cov}(K, K) & \mathrm{cov}(K, Mg) & \dots & \mathrm{cov}(K, SO_4) & \mathrm{cov}(K, PH) \\ \mathrm{cov}(Mg, Na) & \mathrm{cov}(Mg, K) & \mathrm{cov}(Mg, Mg) & \dots & \mathrm{cov}(Mg, SO_4) & \mathrm{cov}(Mg, PH) \\ & & \vdots & & & \vdots \\ \mathrm{cov}(SO_4, Na) & \mathrm{cov}(SO_4, K) & \mathrm{cov}(SO_4, Mg) & \dots & \mathrm{cov}(SO_4, SO_4) & \mathrm{cov}(SO_4, PH) \\ \mathrm{cov}(PH, Na) & \mathrm{cov}(PH, K) & \mathrm{cov}(PH, Mg) & \dots & \mathrm{cov}(PH, SO_4) & \mathrm{cov}(PH, PH) \end{bmatrix}$$

Eigenvector [V] =

0.511	-0.528	-0.12	0.353	0.033	-0.246	-0.177	0.024	-0.062	-0.47	Na
0.476	0.04	0.088	-0.011	-0.296	0.482	-0.513	0.204	0.006	0.37	K
-0.544	-0.27	0.129	0.04	-0.473	0.343	-0.125	0.241	-0.094	-0.432	Mg
-0.082	-0.103	0.12	-0.495	-0.17	-0.339	-0.502	-0.417	0.376	-0.094	Ca
0.377	0.06	-0.1	-0.606	0.0	0.373	0.381	-0.02	0.047	-0.434	Sr
-0.072	0.049	-0.687	-0.061	-0.14	-0.173	-0.02	0.502	0.459	0.049	MnII
0.095	-0.062	0.671	-0.031	0.13	-0.17	0.163	0.517	0.44	-0.016	FeII
0.101	0.785	0.078	0.183	-0.114	-0.185	-0.237	0.092	-0.093	-0.459	Cl
0.14	0.069	0.049	0.384	-0.553	0.061	0.395	-0.399	0.443	0.05	SO4
0.147	-0.05	0.064	-0.27	-0.549	-0.486	0.225	0.19	-0.482	0.202	PH

Construct an Adjusted Data Matrix from the Brine Data Matrix by subtracting the mean of each column.

Adjusted Data Matrix [Am] = [$(X_{ik} - \overline{X}_k)$]

where $\overline{X}_k$ is the mean of brine data column k

X_{ik} is the individual brine data; i=well, k=brine data

Compute the Final Data [F] matrix as the Feature Vector times the transpose of the Adjusted Data matrix,

$[F] = [V] \times [Am]^T$

The Original Data [B] matrix can be found by multiplying the transpose of the Feature Vector $[V]^T$ times the Fine Data [F] matrix plus the Original Mean $[X_o]$,

$[B] = [V]^T \times [F] + [X_o]$.

The above equation also works even if not all the eigenvectors are included in the feature vector.

If the eigenvector is used on the Adjusted Data Matrix and the Original Mean is added back then you would expect to get the original Brine data matrix back.

Good	Na	K	Mg	Ca	Sr	MnII	FeII	Cl	SO4	PH
Mean	2,665.634	9.299	214.667	602.367	10.043	0.033	1.143	3,438.603	26.469	5.493
Sigma	152.374	1.045	33.629	19.478	6.607	0.019	1.383	178.909	8.326	0.416

Below 1	Na	K	Mg	Ca	Sr	MnII	FeII	Cl	SO4	PH
Mean	2,677.727	9.214	211.104	615.492	11.342	0.039	0.918	3,263.849	25.996	5.372
Sigma	122.8	0.936	21.36	20.935	3.693	0.021	0.724	183.52	5.352	0.339

Above 1	Na	K	Mg	Ca	Sr	MnII	FeII	Cl	SO4	PH
Mean	2,259.291	16.556	169.01	507.481	2.278	0.03	0.332	3,206.169	19.403	6.229
Sigma	372.107	9.807	52.16	98.683	3.367	0.015	0.308	565.91	18.376	0.482

The normalization process assumes that the “Good” Data set is correct and that for some reason the measurements Below and Above the 2% of the Anions/Cations ratio of 1.0 have below average values of Chlorides, which could have saturated the measurements results. This analysis is not suggesting that the data is in error only that the Brine data for Below and Above data sets will be modified to fit the “Good” Data set mean value.

The “Good” Data eigenvectors and Means will be used to correct the Brine data for the Below and Above data sets. In the same manner as above, an Adjusted Data Matrix will be constructed for the Below and Above data sets using their respective means. Then the “Good” brine data eigenvectors and “Good” brine data means will be used to compute the “original” data sets as if the above and below were measured as the original good data

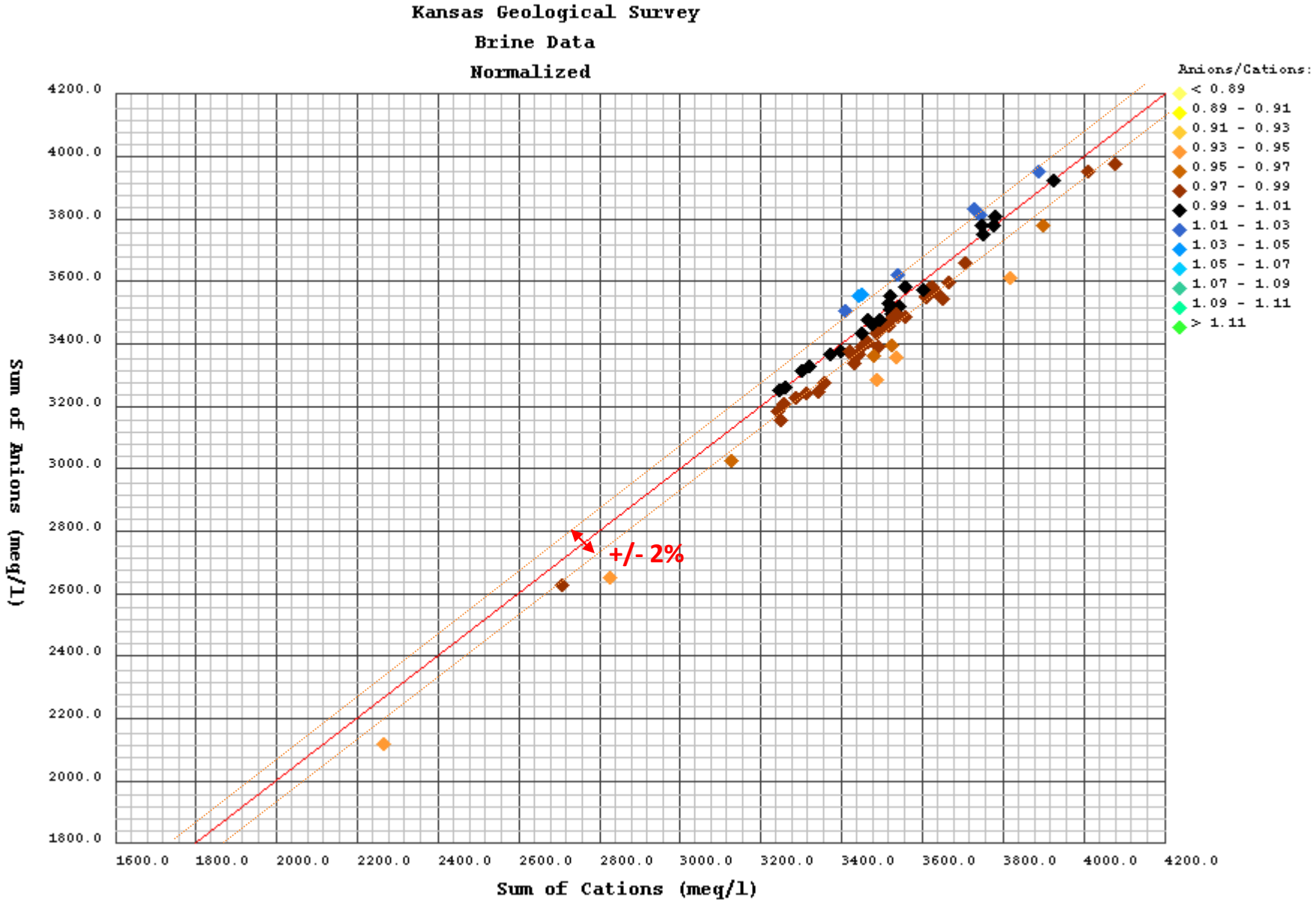
$[B] = [Vg]^T X [[Vg] X [Am_R]^T] + [Xg]$.

where [Vg] is the eigenvector of the “Good” data set

[Xg] is the “Good” mean matrix

$[Am_R]$ is the Adjusted Data Matrix for either the Below or Above data sets.

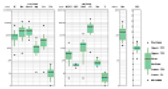
[B] is the “new Original” data set of the Below or Above Brine data.


Kansas Geological Survey
Brine Data
Normalized
Anions/Cations:
< 0.89
0.89 - 0.91
0.91 - 0.93
0.93 - 0.95
0.95 - 0.97
0.97 - 0.99
0.99 - 1.01
1.01 - 1.03
1.03 - 1.05
1.05 - 1.07
1.07 - 1.09
1.09 - 1.11
> 1.11
+/- 2%
Sum of Anions (meq/l)
4200.0
4000.0
3800.0
3600.0
3400.0
3200.0
3000.0
2800.0
2600.0
2400.0
2200.0
2000.0
1800.0
Sum of Cations (meq/l)
1600.0
1800.0
2000.0
2200.0
2400.0
2600.0
2800.0
3000.0
3200.0
3400.0
3600.0
3800.0
4000.0
4200.0

South-central Kansas CO_2 Project
Brine Data Summary Page

Create a Comma Separated Values (CSV) Web Page: Wellington.csv

Piper Diagram



NOTE: Click on the icons to the left for summary plots of data or the icons under the "Sample Plot" and "Piper Diagram" columns to launch the Java Web Apps for the individual well brine data.

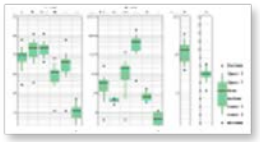
Also you will need a JAVA JRE on your PC to run the web apps, you can download it free from java.com.

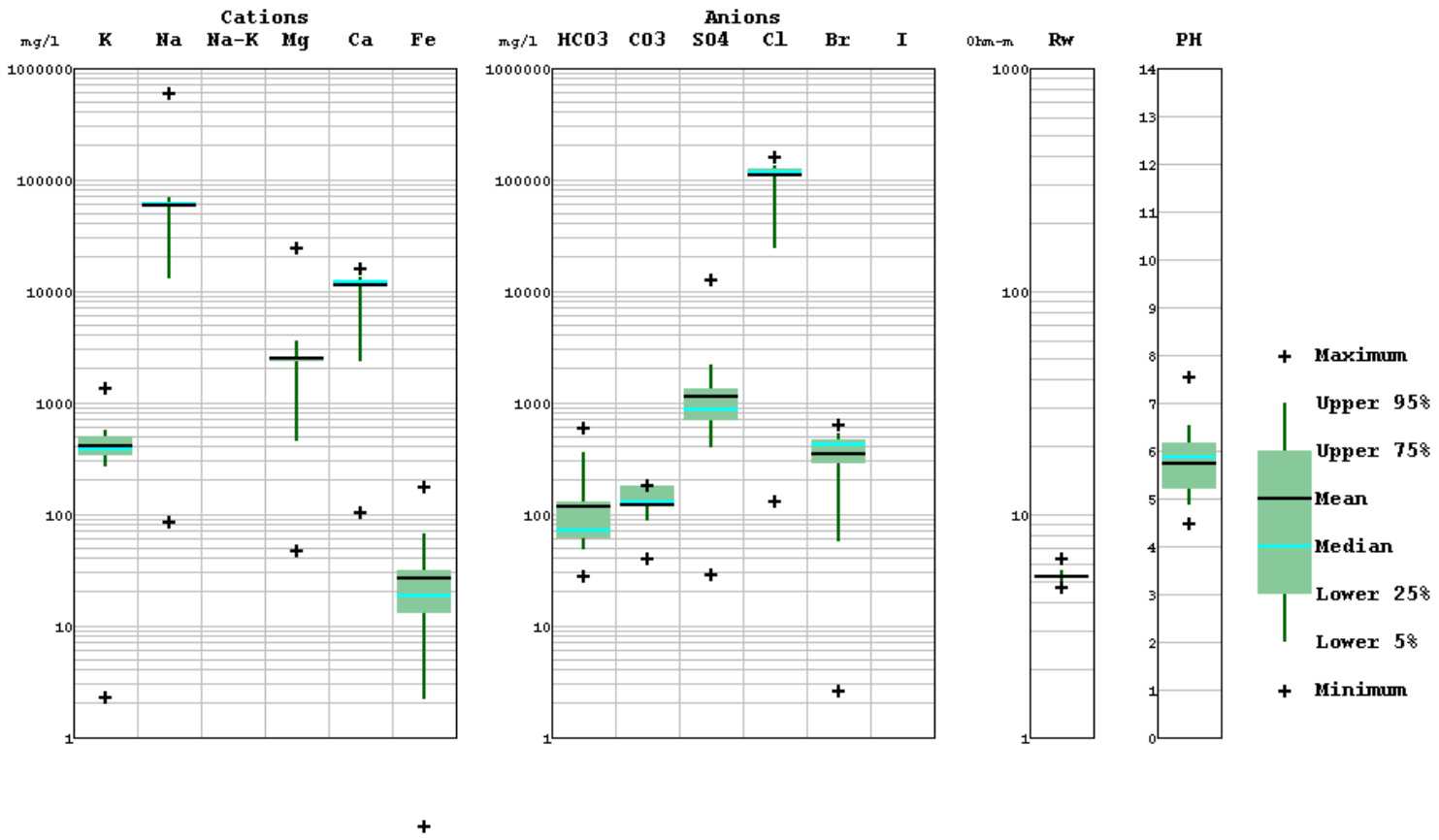
Well		Location			Elevation			Total	Well		Cations (Records)							Anions (Records)						
Name	API-Number	TRS	Latitude	Longitude	GL	KB	DF	Depth	Status	PH	Ca	Mg	Sr	Na	K	Fe	Mn	Cl	Br	I	SO4	CO3	HCO3	BO3
Cole 2	15-191-21179	T31S R1W S28	37.3186181	-97.4222009	1266	1277		3900	OIL	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1
Cole 1	15-191-21000	T31S R1W S28	37.3186655	-97.4244707		1284		4156	OIL	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1
Erker 4	15-191-10132	T31S R1W S33	37.3113585	-97.4313515			1255	3688	OIL	1	1	1	0	1	0	0	0	1	0	0	0	0	1	0
Erker 5	15-191-10133	T31S R1W S33	37.3113613	-97.4347555			1250	3877	OIL	1	1	1	0	1	0	0	0	1	0	0	1	0	1	0
Markley 'B' 1	15-191-10075	T31S R1W S32	37.303968	-97.4496146			1239	3701	OIL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wellington Kgs 1-28	15-191-22590	T31S R1W S28	37.3194833	-97.433378	1257	1270		5250	OTHER	4	4	4	4	4	4	4	4	4	4	0	4	3	0	0
Wellington Kgs 1-32	15-191-22591	T31S R1W S32	37.315444	-97.442414	1259	1272	1270	5240	OTHER	4	4	4	4	4	4	4	4	4	4	0	4	4	0	0
Wellington Unit 'A' 136	15-191-00395-0001	T31S R1W S33	37.3168299	-97.4376423	1259			3699	OIL	27	7	7	7	7	7	7	3	4	1	0	4	0	27	3
Wellington Unit 36	15-191-19005	T31S R1W S32	37.316789	-97.4404585	1266			3700	OIL	30	8	8	8	8	8	8	6	5	0	0	5	0	29	5
Wellington Unit 45	15-191-10083-0002	T31S R1W S32	37.3149436	-97.4427392				3696	OIL	39	10	10	9	10	10	10	6	8	3	0	8	0	30	5
Wellington Kgs 2-32	15-191-22770	T31S R1W S32	37.3105345	-97.4418	1257	1269	1267	3860	EOR	5	3	3	0	3	3	4	3	5	3	0	5	0	0	0
Wellington Unit 100	15-191-10281	T32S R1W S5	37.3000928	-97.4405128			1223	3683	OIL	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1
Wellington Unit 102	15-191-10257	T32S R1W S4	37.3004292	-97.4291577			1246	3695	OIL	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1
Wellington Unit 106	15-191-10259	T32S R1W S4	37.2988754	-97.4253874			1243	3691	OIL	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1

http://chasm.kgs.ku.edu/ords/iqstrat.co2_brine_summary_pkg.build_top_web_page?field=Wellington

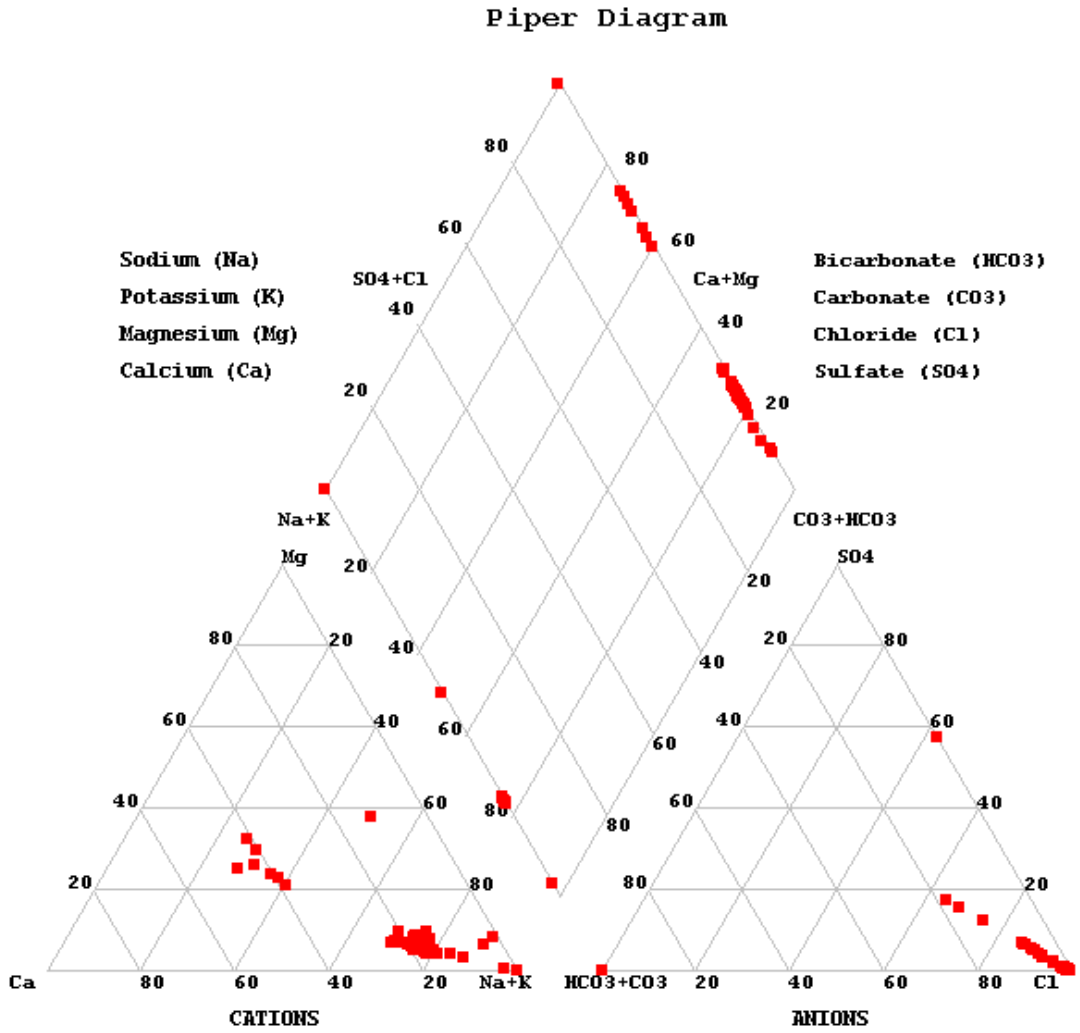
- List of all Wells in the Project Area with Brine sample data.
- Well Name Column is a URL Link to view the Summary Page for a specific well.
- Summary page lists the location of the well and “Count” of brine sample records.
- User can click on the Wellington.csv URL Link to generate a “Comma Separated Values” CSV file page.
- 2 Applets are provided at the top of the page to plot all the complete brine sample well data

Wellington Field CO2 Brine Data Summary Page





Concentration Plot: Box and whiskers plot showing the distributions of the measured concentrations. Boxes extend from the 25th to the 75th percentile, horizontal bars inside the boxes represent the median and the mean, vertical line to the 5th and 95th percentile and the maximum and minimum observations presented as crosses.



Piper Diagram: The Piper diagram plots the major ions as percentages of milli-equivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto an adjacent grid. This plot reveals useful properties and relationships for large sample groups. The main purpose of the Piper diagram is to show clustering of data points to indicate samples that have similar compositions.

South-central Kansas CO_2 Project
Brine Data Summary Page
WELLINGTON UNIT 45 (15-191-10083-0002) [T31S R1W S32]

Fluid Level Summary Data for Wellington Unit 45 (15-191-10083-0002)

Piper Diagram

NOTE: Click on the icons to the left for summary plots of data or the icons under the "Sample Plot" and "Piper Diagram" columns to launch the Java Web Apps for the individual well brine data.

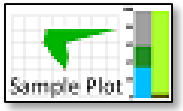
Also you will need a JAVA JRE on your PC to run the web apps, you can download it free from java.com.

Display		Sample	Formation	Depths			Temp	Cations (mg/L)							Anions (mg/L)							Computed	Sample	Piper
Summary	ID	Date	Name	Top	Base	PH	deg C	Ca	Mg	Sr	Na	K	Fe	Mn	Cl	Br	I	SO4	CO3	HCO3	BO3	TDS	Plot	Diagram
Lab	0	05/12/2015 00:00	Mississippian	3600	3600	5.2		11621.6	2449.3	432.4	56748.9	404.4	41.8	1.9	107818			1660		73.2	44.6	181296.1	Sample Plot	Piper Diagram
Lab	2	06/17/2015 00:00	Mississippian	3650		6.31		10800	2280		53400	478	17.4	.78	117000	390		682				185048.81	Sample Plot	Piper Diagram
Lab	3	01/19/2016 00:00	Mississippian	3600	3600	6.5		11919.5	2444.2	433.5	55444.4	354	18.7	.8	123900			968		48.8	44	195575.9	Sample Plot	Piper Diagram
Field		01/19/2016 00:00																						
Field		01/19/2016 00:00																						
Lab		01/20/2016 00:00	Mississippian	3600	3600	6.2		12241.17	2458.387	411.1175	60530.51	541.4041	19		121229.3	428		767.84		68.1		198750.7286	Sample Plot	Piper Diagram
Field	0	01/20/2016 00:00				5.43	23.3													68.14				
Lab	4	01/27/2016 00:00	Mississippian	3600	3600	6.2		12029.13	2441.28	409.4981	59763.48	537.9642	15		121789.2	438		768.4		64.9		198294.3523	Sample Plot	Piper Diagram

- List of Brine samples for Well (Wellington Unit 45)
- Display Summary Column is a URL Link to view the brine data for a specific Sample Date.
- Summary page lists summary brine data values.
- User can click on the Wellington Unit 45 … .csv URL Link to generate a “Comma Separated Values” CSV file page of the Brine Data Sample for the Wellington Unit 45.
- 2 Applets are provided for the Laboratory Data Samples in the far right columns.

Brine Sample Plot

Well: WELLINGTON UNIT 45 (15-191-10083-0002)



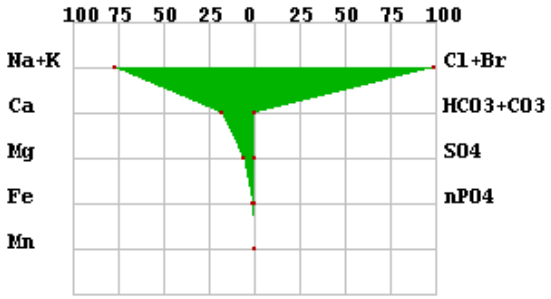
Kansas Geological Survey
1930 Constant Avenue
Lawrence, Kansas
66047

Formation: Mississippian
Depth: 3600.0 - 3600.0

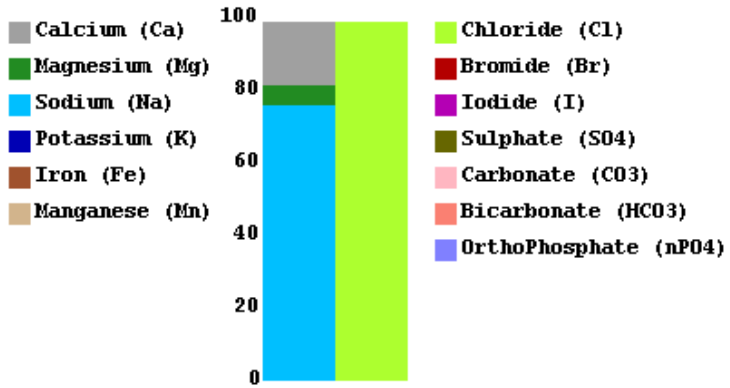
Sample Date: 01/20/2016 00:00

Unit	Ca	Mg	Na	K	Fe	Mn	Cl	Br	I	SO4	HCO3	CO3	nPO4
mg/l	12241.17	2458.387	60530.51	541.4041	19.0		121229.3	428.0		767.84	68.1		
meq/l	610.83	202.33	2632.9	13.84	0.68		3419.72	5.35		15.98	1.11		
% meq/l	17.65	5.84	76.08	0.39	0.01		99.34	0.15		0.46	0.03		

Stiff Diagram



Collins Bar Diagram



General Analysis

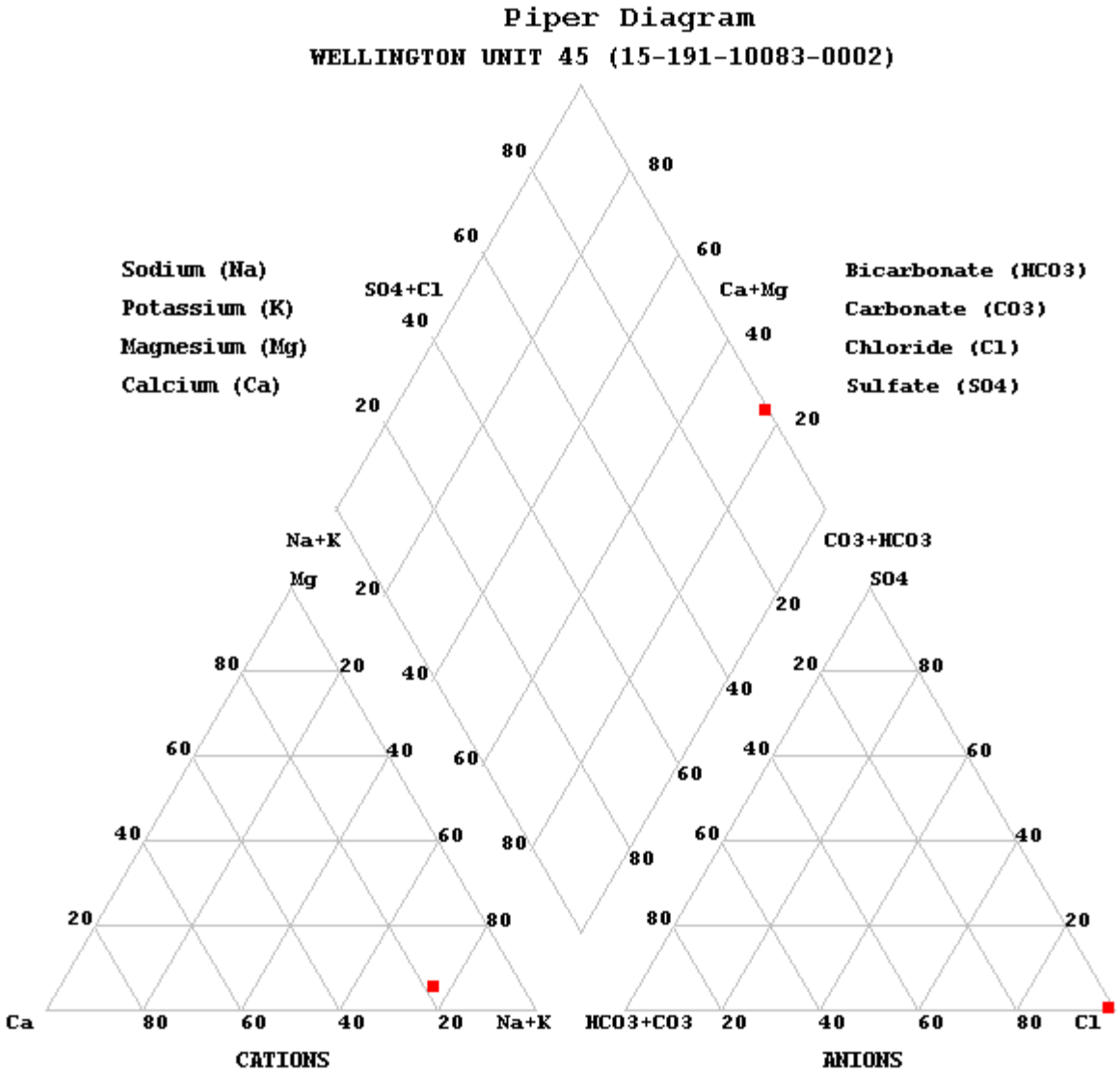
PH: 6.2

Anion/Cation Ratio: 0.99

Computed Total Solids: 198716.0 mg/L

Stiff Diagram: The Stiff diagram is a graphical representation of brine fluid, first developed by H.A.Stiff in 1951. It is usually plotted without the labeled axis and is useful making visual comparison of waters with different characteristics. The patterns tend to maintain its shape upon concentration or dilution.

Collins Bar Diagram: Collins diagrams (Collins 1923) present the relative major ion composition in percent milliequivalent per liter. Both the cations and anions have a total of 100 %. The bar diagram used in the Brine Sample Plot, the cations are plotted on the left and the anions are plotted on the right.



Piper Diagram: The Piper diagram plots the major ions as percentages of milli-equivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto an adjacent grid. This plot reveals useful properties and relationships for large sample groups. The main purpose of the Piper diagram is to show clustering of data points to indicate samples that have similar compositions.

South-central Kansas CO_2 Project
WELLINGTON UNIT 45
Brine Data

Lease: WELLINGTON UNIT 45
API-Number: 15-191-10083-0002
Location: T31S R1W S32
Longitude: -97.4427392
Latitude: 37.3149436

Laboratory
Kansas Geological Survey
1930 Constant Avenue
Lawrence, Kansas 66047

Sample Date: 01/20/2016 00:00 **Recieved Date:** **Report Date:**

Description: Analyst Christa Jackson

Field Data

Data Description	Value	units
pH Lab	6.2	
Formation	Mississippian	
TOP	3600	ft
BASE	3600	ft

Calculated TDS (mg/L) = 198716 mg/L

Analysis of Sample

Data Anions	Value	units
Fluoride	3	mg/L
Chloride	121229.3	mg/L
Bromide	428	mg/L
Bicarbonate	68.1	mg/L
Nitrate	42	mg/L
Sulfate	767.84	mg/L

Anion/Cation Ratio = .99

Data Cations	Value	units
Lithium	10.9	mg/L
Sodium	60530.51	mg/L
Potassium	541.4041	mg/L
Magnesium	2458.387	mg/L
Calcium	12241.17	mg/L
Strontium	411.1175	mg/L
Iron(II)	19	mg/L

Click icon images below to display web apps:

Sample Plot & Piper Diagram

Sample Plot Piper Diagram

Note: You will need a JAVA JRE on your PC to run the web apps, you can download it free from java.com.

- List of data measured for the Well (Wellington Unit 45) at a specific date (1/20/2016).
- 2 Applets are provided for the Laboratory Data Sample at the bottom of the page.

South-central Kansas CO_2 Project
Fluid Level Data

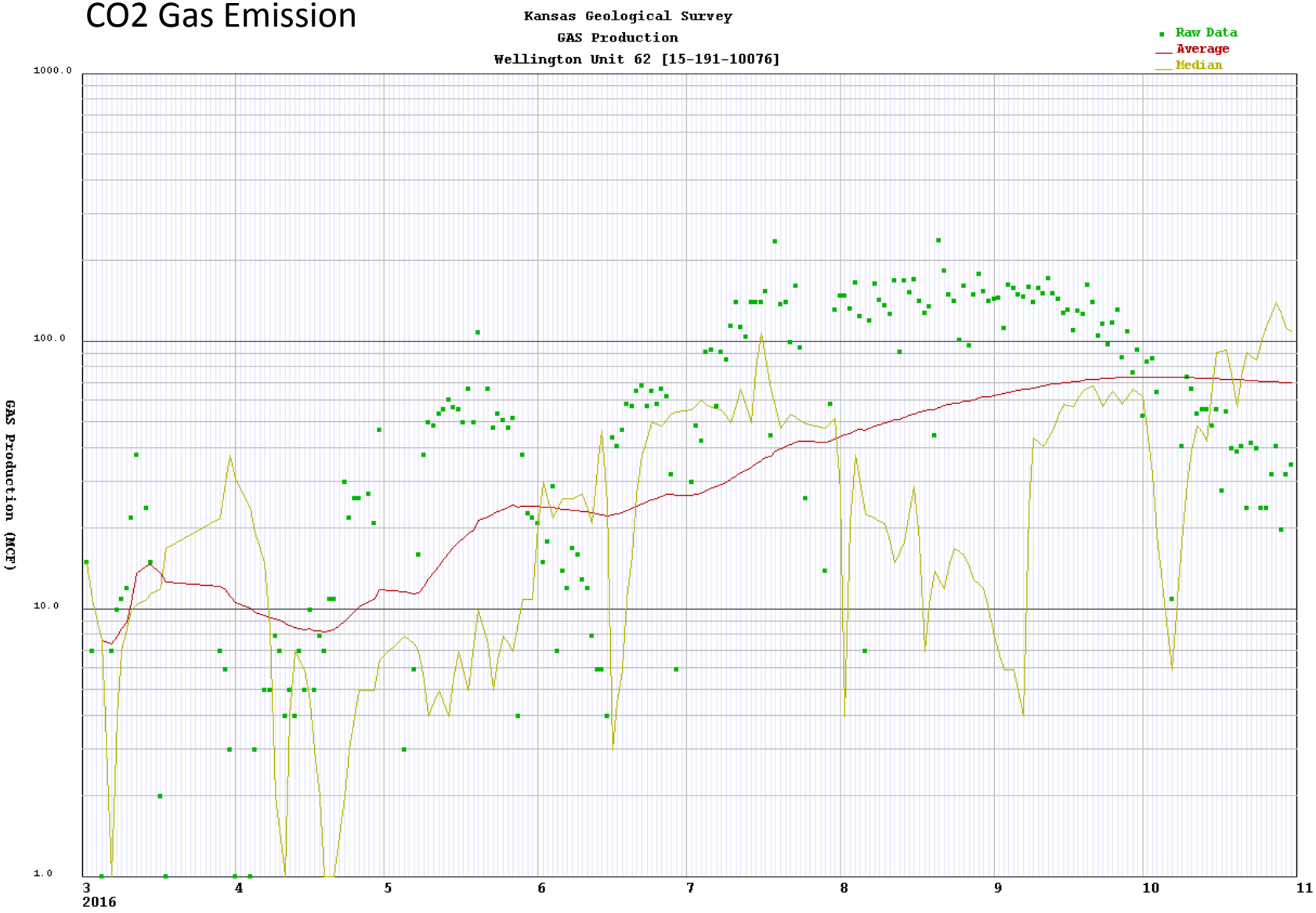
Fluid Level Data Summary Page

Create a Comma Separated Values (CSV) Web Page for Fluid Level: Fluid_Level.csv
Create a Comma Separated Values (CSV) Web Page for CO2 Offset Gas: CO2_Offset_Gas.csv

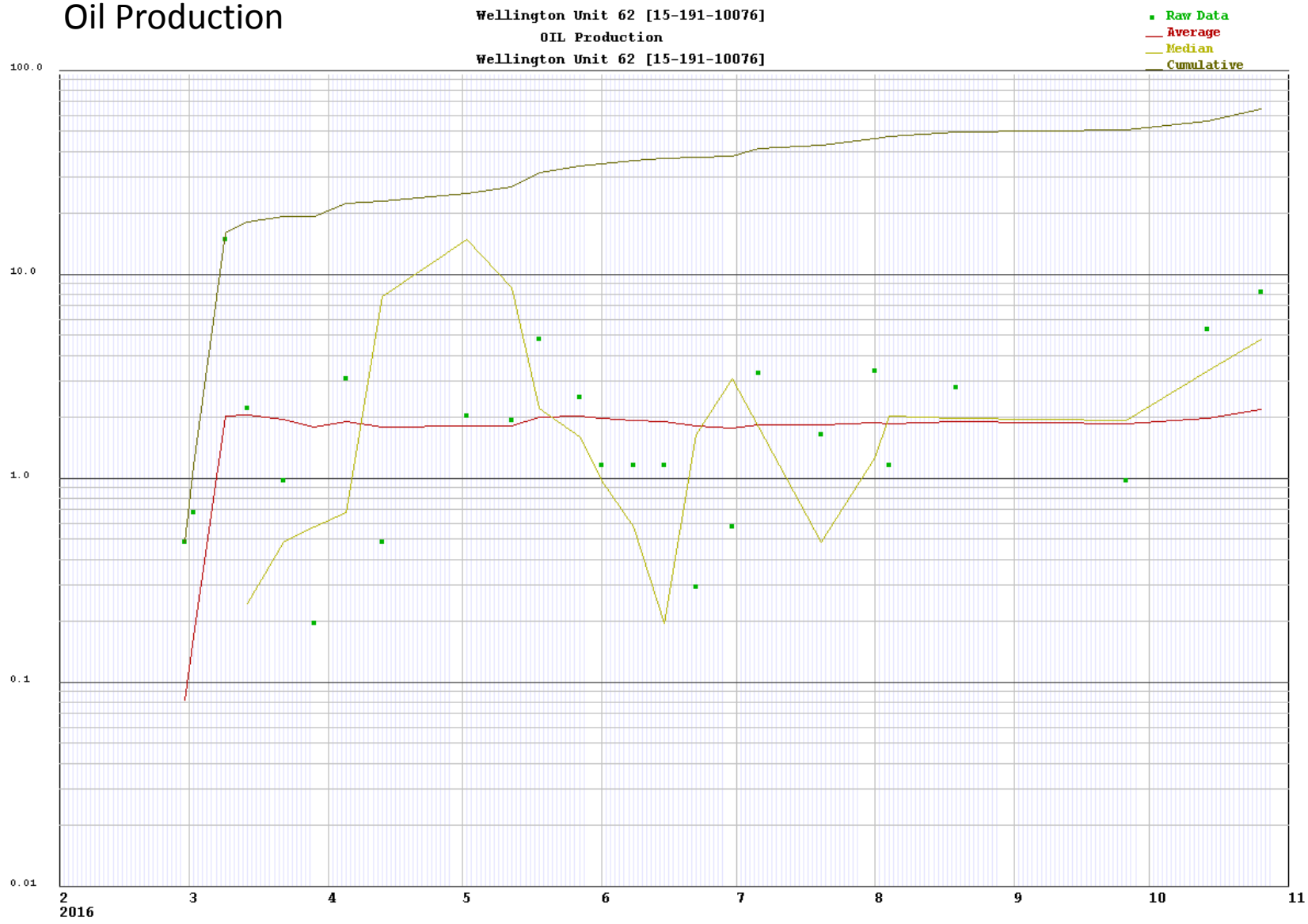
Producers Test Data										
Well		Location			Elevation			Total	Well	Production
Name	API-Number	TRS	Latitude	Longitude	GL	KB	DF	Depth	Status	Plot
Wellington Unit 45	15-191-10083-0002	T31S R1W S32	37.3149436	-97.4427392				3696	OIL	Production
Wellington Kgs 2-32	15-191-22770	T31S R1W S32	37.3105345	-97.4418	1257	1269	1267	3860	EOR	Production
Wellington Unit 35	15-191-10077	T31S R1W S32	37.3167567	-97.4427281			1269	3711	OIL	
Wellington Unit 47	15-191-10134	T31S R1W S33	37.313177	-97.4381385			1262	3694	OIL	Production
Wellington Unit 53	15-191-10078	T31S R1W S32	37.3113174	-97.4427614			1255	3693	OIL	Production
Wellington Unit 60	15-191-10093	T31S R1W S32	37.3094396	-97.4473117			1238	3700	OIL	Production
Wellington Unit 61	15-191-10087	T31S R1W S32	37.3095043	-97.4427725			1258	3697	OIL	Production
Wellington Unit 62	15-191-10076	T31S R1W S32	37.3095366	-97.4405029			1264	3686	OIL	Production
Wellington Unit 63	15-191-11442	T31S R1W S33	37.3095512	-97.4381806			1249	3675	OIL	Production
Wellington Unit 69	15-191-10092	T31S R1W S32	37.3076589	-97.4450532			1248	3696	OIL	Production
Nelson East		T R S							TANK	Production

- List of all Monitoring Wells in the Project Area with Fluid Level data.
- Well Name Column is a URL Link to view the Summary Page for a specific well.
- User can click on the Fluid Level & CO2_Offset_Gas URL Links to generate a “Comma Separated Values” CSV file page.
- Production Plot Column will produce a Oil Production/CO2 Emissions or CO2/Brine Injection Plots.

CO2 Gas Emission



Oil Production



South-central Kansas CO_2 Project
Fluid Level Data
Producers Test Data Summary Page
Wellington Unit 62 (15-191-10076) [T31S R1W S32]

Brine Summary Data for Wellington Unit 62 (15-191-10076)

Create a Comma Separated Values (CSV) Web Page for Fluid Level: Fluid_Level.csv
Create a Comma Separated Values (CSV) Web Page for CO2 Offset Gas: CO2_Offset_Gas.csv

Test Date	Group ID	Group No	Total Fluid (bbl)	Oil Cut (%)	Barrels of Oil Per Day	Fluid Level (ft)	Joints in Well	Bottom Hole Pressure (psig)
01 August 2015	FLUID	0	160	1	0	117	117	0
01 September 2015	FLUID	1	160	1	0	117	117	0
01 October 2015	FLUID	2	0	0	0	39	117	1208.81
01 November 2015	FLUID	3	0	0	0	32	117	1317.42
01 December 2015	FLUID	4	0	0	0	29	117	1363.97
01 January 2016	FLUID	5	0	0	0	23	117	1457.07
05 February 2016	FLUID	6	85	.0001	.000085	37	117	1232
09 February 2016	FLUID	7	129	.0001	.000129	39	117	1201
18 February 2016	FLUID	8	115	.0001	.000115	39	117	1201
22 February 2016	FLUID	9	114.6	.0001	.0001146	45	117	1109
26 February 2016	FLUID	10	100.3	.00001	.00001003	38	117	1217

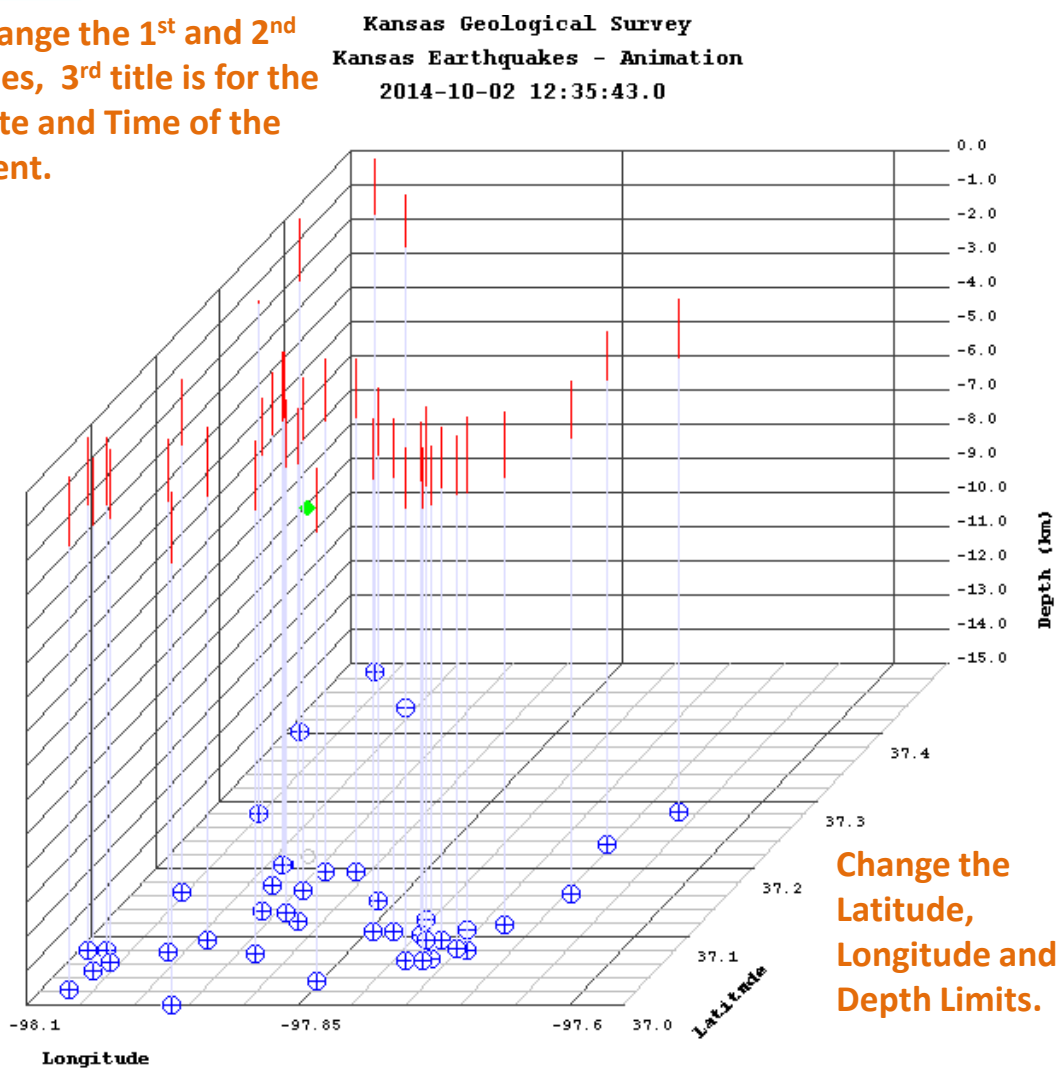
- List of all Fluid Level data for Wellington Unit 62.
- Fluid Level & CO2 Offset Gas CSV URL links to create Comma Separated Values (CSV) Web Page of data.

Earthquake 3D Plot -Animation

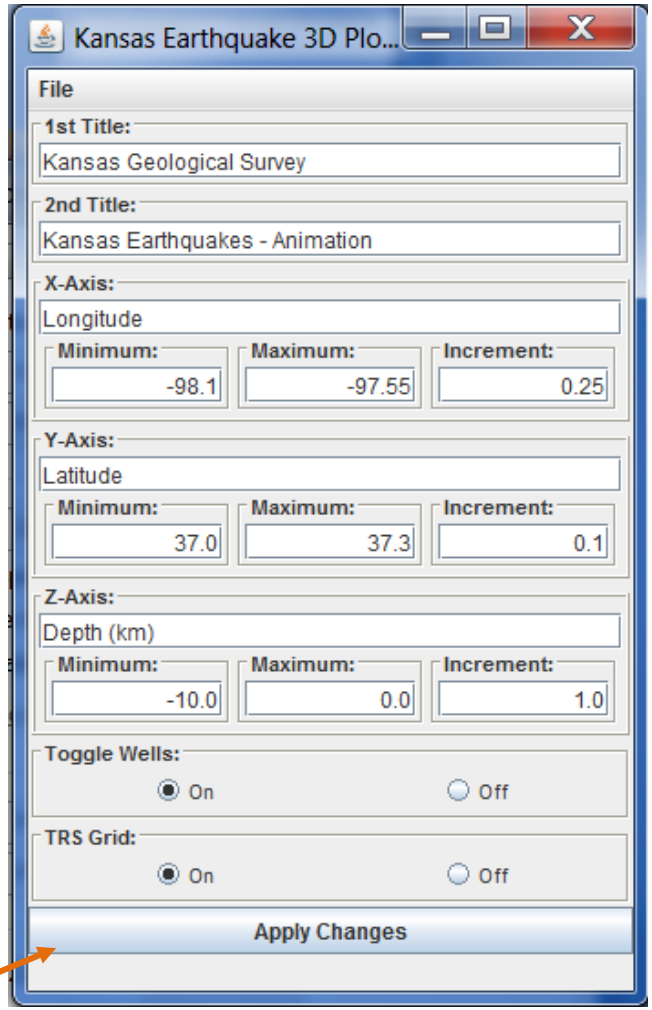
This applet is a animated 2 & 3 dimensional plot of Kansas Earthquakes in Sumner and Harper Counties. The Earthquake data is stored in the "gis_webinfo earthquakes" ORACLE Database Table on the Kansas Geological Server. The Animation Control Dialog will allow the user to change the limits of Latitude, Longitude and Depth ranges and to turn on or off the well symbols in the plot.

The plot displays the data collected from 17 July 2014 to present. The data is accessed using an ORACLE PL/SQL Stored Procedure

Change the 1st and 2nd titles, 3rd title is for the Date and Time of the Event.



Each earthquake is colored by its magnitude.



Change the Latitude, Longitude and Depth Limits.

Well Symbols can be toggled on or off.

Symbol	Description
⊕	SWD – Salt Water Disposal Well
|	SWD Well Surface to TD
◆	Earthquake Data

Apply Changes – Retrieves the users changes from the Limits Dialog and transfers the data to the 2D & 3D Plots.

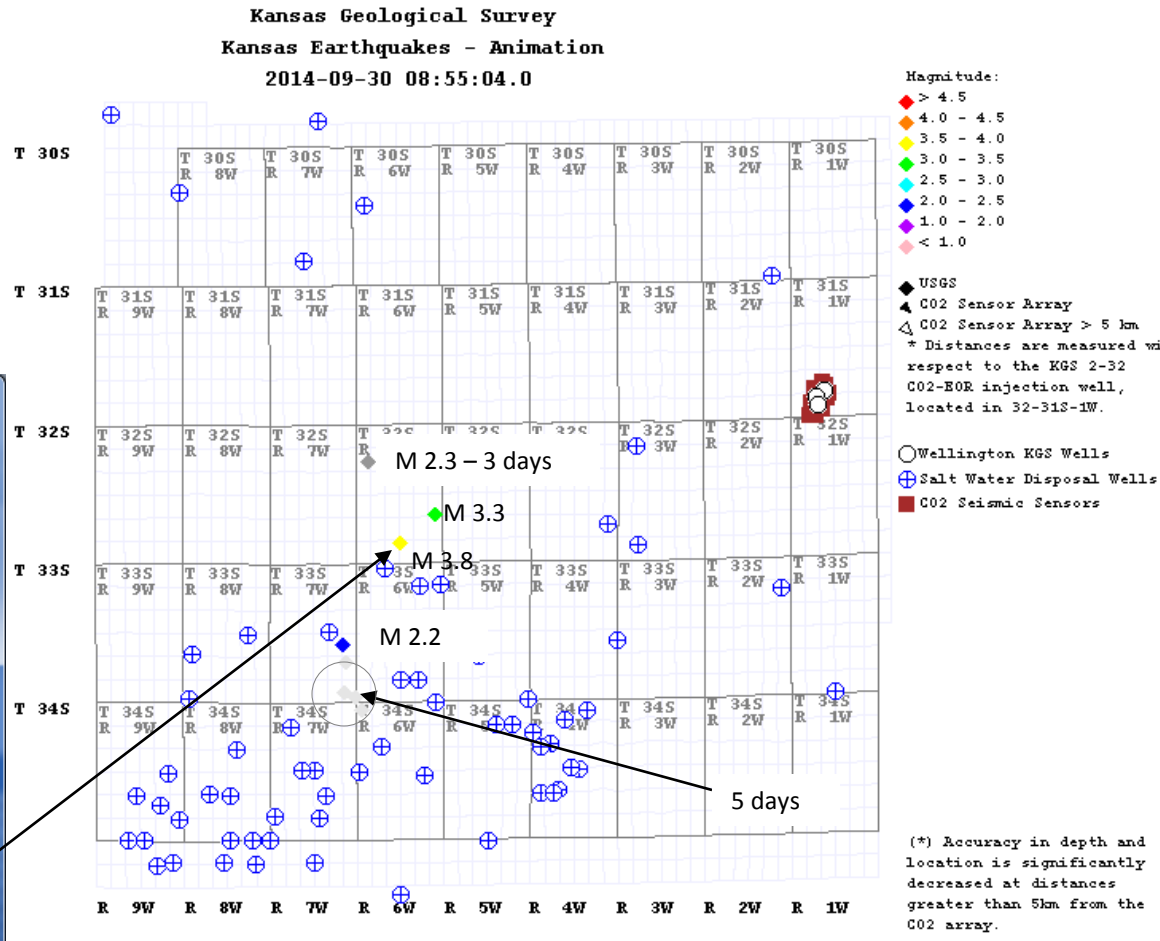
Highlight the event you wish to display and click on the “Select” button to display it in the 2D & 3D Plots.

The Event and the previous 5 days are displayed on the plot. 1 to 5 days are plotted as shades of gray.

Select Status of Data

Date	Magnit...	Latitude	Longitude	Depth ...	Source
2014-07-17 04:40:43.0	3.6	37.1018	-97.8075	-5.0	USGS
2014-07-19 18:24:58.0	3.0	37.224	-97.9469	-5.53	USGS
2014-07-20 06:24:58.0	3.3	37.3406	-98.1023	-4.59	USGS
2014-07-25 01:17:24.0	2.4	37.0291	-97.818	-5.0	USGS
2014-07-26 04:57:10.0	3.4	37.1165	-97.8044	-2.77	USGS
2014-07-27 19:14:48.0	2.1	37.0309	-97.9081	-4.5	USGS
2014-08-04 06:50:27.0	2.5	37.2309	-97.9854	-4.85	USGS
2014-08-10 15:23:12.0	2.2	37.1893	-97.9751	-5.0	USGS
2014-08-20 10:33:58.0	3.1	37.2481	-97.9628	-6.76	USGS
2014-08-24 18:10:05.0	3.0	37.3735	-98.1086	-8.67	USGS
2014-08-27 09:11:25.0	2.8	37.0455	-97.8518	-5.0	USGS
2014-09-08 06:56:52.0	3.4	37.262	-97.6345	-4.92	USGS
2014-09-08 09:23:30.0	3.1	37.2714	-97.6235	-6.55	USGS
2014-09-17 08:42:32.0	2.2	37.1133	-97.9936	-5.0	USGS
2014-09-17 09:11:19.0	2.2	37.1305	-98.0142	-5.0	USGS
2014-09-25 00:46:24.0	2.8	37.1177	-98.0197	-5.0	USGS
2014-09-25 09:43:23.0	2.5	37.118	-98.0134	-5.0	USGS
2014-09-25 15:04:55.0	2.5	37.1482	-98.0323	-5.0	USGS
2014-09-25 19:34:41.0	2.4	37.1269	-98.0202	-5.0	USGS
2014-09-25 20:14:24.0	2.0	37.1296	-98.0357	-5.0	USGS
2014-09-27 14:46:45.0	2.3	37.2747	-98.0049	-5.0	USGS
2014-09-30 05:18:35.0	2.2	37.1595	-98.0366	-5.0	USGS
2014-09-30 06:30:26.0	3.3	37.2415	-97.9207	-7.73	USGS
2014-09-30 08:55:04.0	3.8	37.2235	-97.964	-3.61	USGS
2014-09-30 09:24:31.0	3.1	37.2474	-97.9414	-4.18	USGS
2014-09-30 10:47:58.0	3.2	37.2359	-97.9677	-5.0	USGS
2014-09-30 11:47:22.0	2.6	37.2611	-97.9552	-5.0	USGS
2014-09-30 12:49:52.0	2.9	37.2453	-97.9565	-8.03	USGS
2014-09-30 18:33:28.0	3.0	37.3854	-95.3831	-5.0	USGS
2014-10-01 00:11:06.0	3.3	37.2243	-97.8898	-5.0	USGS
2014-10-02 12:01:24.0	4.3	37.2382	-97.9536	-5.0	USGS
2014-10-02 12:02:55.0	3.5	37.2332	-97.9668	-5.0	USGS
2014-10-02 12:03:09.0	2.9	37.227	-97.9502	-5.0	USGS
2014-10-02 12:03:43.0	3.1	37.2329	-97.9747	-5.0	USGS
2014-10-02 12:35:43.0	3.4	37.228	-97.9753	-5.0	USGS
2014-10-02 16:50:49.0	3.1	37.2357	-97.9608	-5.0	USGS
2014-10-03 04:23:18.0	2.7	37.2406	-97.9751	-3.39	USGS
2014-10-06 06:30:52.0	2.7	37.2411	-97.9743	-5.0	USGS
2014-10-09 09:41:41.0	2.7	37.2423	-97.9746	-7.85	USGS
2014-10-09 22:58:51.0	3.3	37.006	-97.9635	-5.0	USGS

Select Cancel



In this example the event of interest is at 9/30/2014 8:55 M 3.8

All previous events that occur on 9/30/2014 will retain their color, e.g. 9/30/2014 6:30 M 3.3 and 9/30/2014 5:18 M 2.2

All other previous events that occur before 9/30/2014 are shades of gray, e.g.
9/27/2014 14:46 M 2.3 dark gray
9/25/2015 20:14 M 2.0 very light gray

Pressure Catalog Summary Page

South-central Kansas CO_2 Project
CO_2 Sequestration
Pressure Catalog Summary Page

Pressure Measured: Date Time (Central)		Aquifer for Wellington KGS 1-28			Pressure Slope		Correction	Barometric				Display
Start	End	Porosity [PU]	Temp [deg F]	Cw [1/GPa]	Start [psig]	End [psig]	Phase [deg]	Efficiency	Earth	Air	Water	Plot
25 APRIL 2016 13:50:00	29 APRIL 2016 23:59:59	.09	133.01	.4437	2121.66	2121.97	-30			2	2	Plot
30 APRIL 2016 00:00:00	05 MAY 2016 14:49:32	.09	133.01	.4437	2121.94	2122.02	-70					Plot
05 MAY 2016 15:40:00	12 MAY 2016 10:58:31	.09	133.01	.4437	2122	2122.11	165			2		Plot
12 MAY 2016 10:58:31	18 MAY 2016 08:14:46	.09	133.01	.4437	2122.05	2122.2	110	.3		2		Plot
18 MAY 2016 08:23:00	25 MAY 2016 13:47:15	.09	133.01	.4437	2121.77	2121.8	-110			2		Plot
25 MAY 2016 13:47:14	31 MAY 2016 22:09:52	.09	133.01	.4437	2121.83	2121.94	-10			3		Plot
31 MAY 2016 22:19:00	07 JUNE 2016 16:17:40	.09	133.01	.4437	2122.39	2122.44	-69					Plot
07 JUNE 2016 16:17:41	15 JUNE 2016 08:13:23	.09	133.01	.4437	2122.77	2122.82	210					Plot
15 JUNE 2016 09:36:00	23 JUNE 2016 07:43:14	.09	133.01	.4437	2122.19	2122.32	120			1		Plot
23 JUNE 2016 07:43:16	29 JUNE 2016 14:58:02	.09	133.01	.4437	2122.28	2122.38	100			2		Plot
08 JULY 2016 12:20:00	15 JULY 2016 22:21:16	.09	133.01	.4437	2122.93	2123.04	185			1		Plot
15 JULY 2016 22:21:17	22 JULY 2016 16:43:20	.09	133.01	.4437	2123.04	2123.1	-25					Plot
29 JULY 2016 17:08:05	06 AUGUST 2016 02:43:50	.09	133.01	.4437	2122.77	2122.88	-88			2		Plot
06 AUGUST 2016 15:42:00	12 AUGUST 2016 22:11:18	.09	133.01	.4437	2123.34	2123.45	80			2	2	Plot
12 AUGUST 2016 22:11:18	20 AUGUST 2016 00:35:57	.09	133.01	.4437	2123.45	2123.48	-180			1	1	Plot
20 AUGUST 2016 00:43:00	27 AUGUST 2016 13:15:51	.09	133.01	.4437	2123.1	2123.17	52			2		Plot
27 AUGUST 2016 13:15:51	02 SEPTEMBER 2016 23:09:48	.09	133.01	.4437	2123.2	2123.23	-115			2		Plot
02 SEPTEMBER 2016 23:18:00	09 SEPTEMBER 2016 17:18:24	.09	133.01	.4437	2123.68	2123.7	-140		1	1	1	Plot
09 SEPTEMBER 2016 17:18:25	16 SEPTEMBER 2016 19:39:45	.09	133.01	.4437	2123.72	2123.73	-45			2	1	Plot
16 SEPTEMBER 2016 19:43:00	23 SEPTEMBER 2016 15:47:15	.09	133.01	.4437	2123.3	2123.3	3					Plot

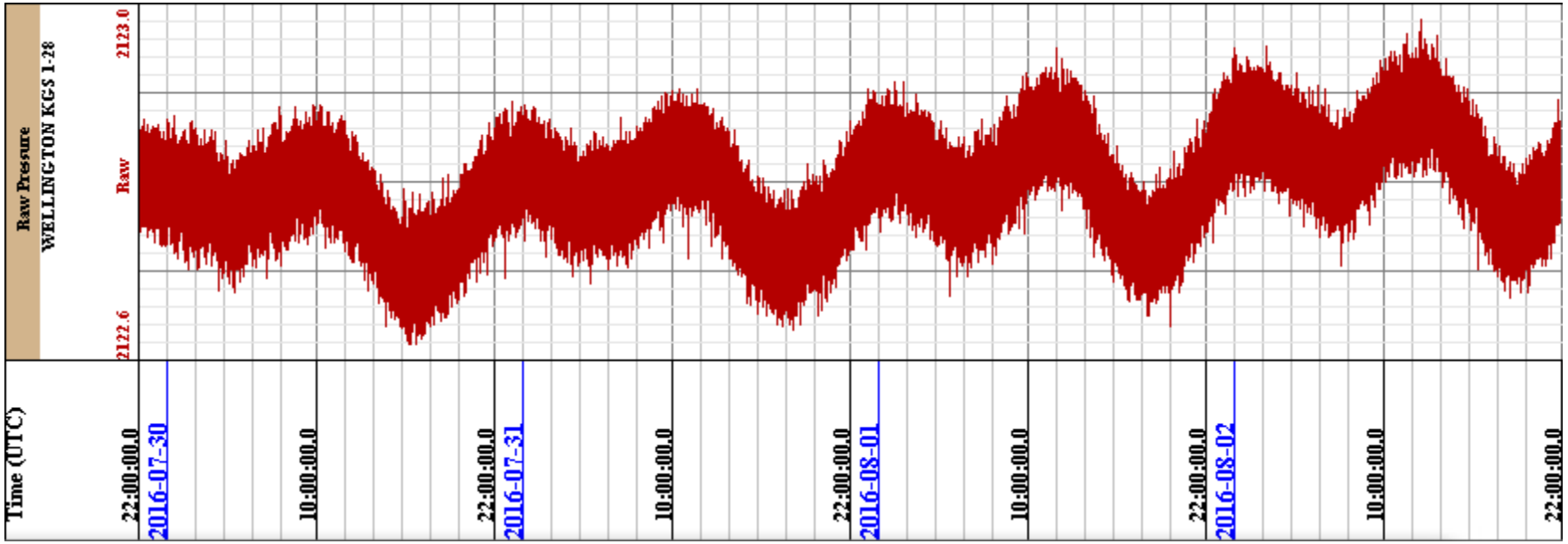
The Pressure Catalog Summary Page uses the PSI_Tides Java Application to generate the Pressure Profile Plots for each weeks data. To view the data click on the Display Plot column next to the week of interest.

Pressure Catalog Summary Page

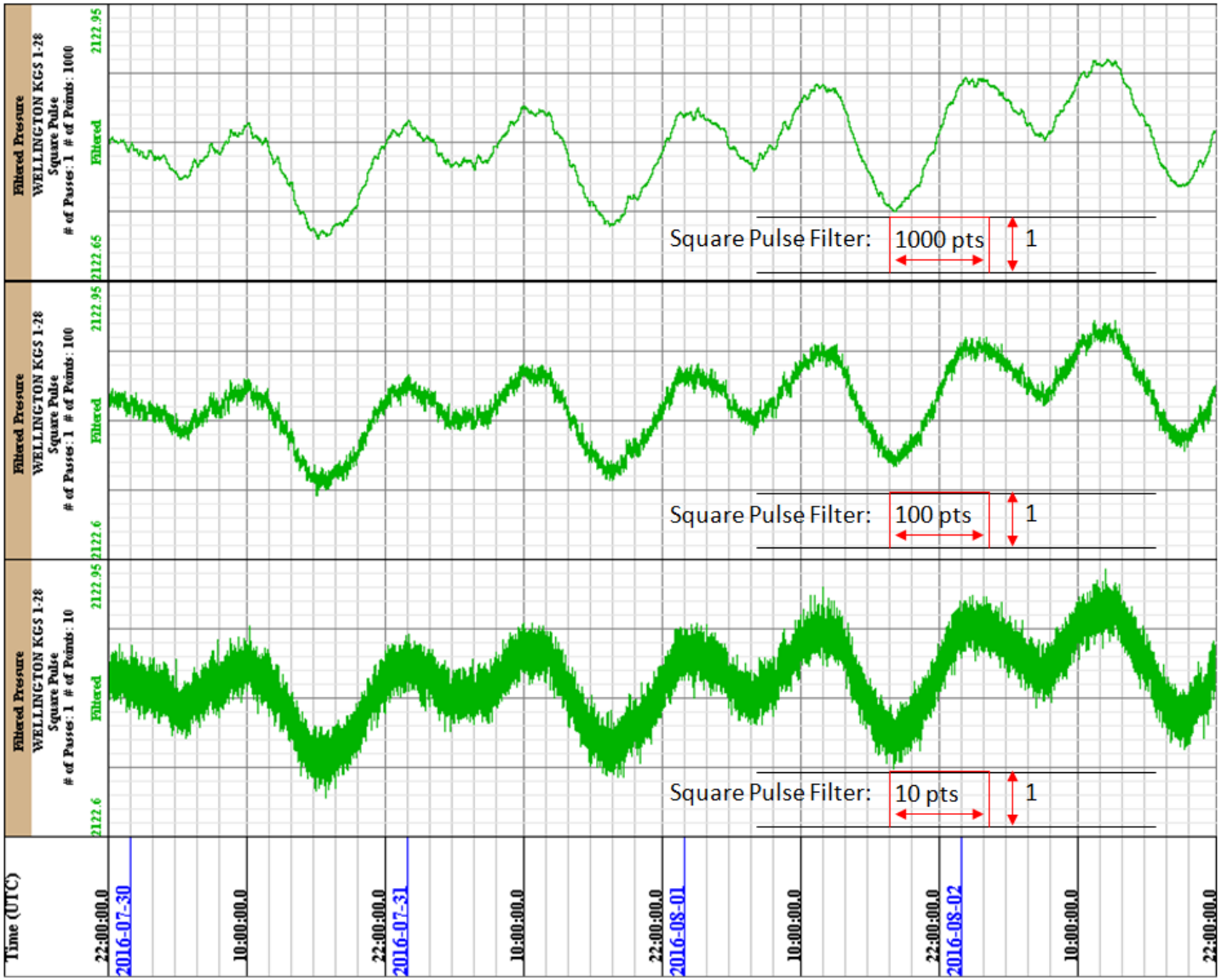
PSI_Tides Java Application

Not released

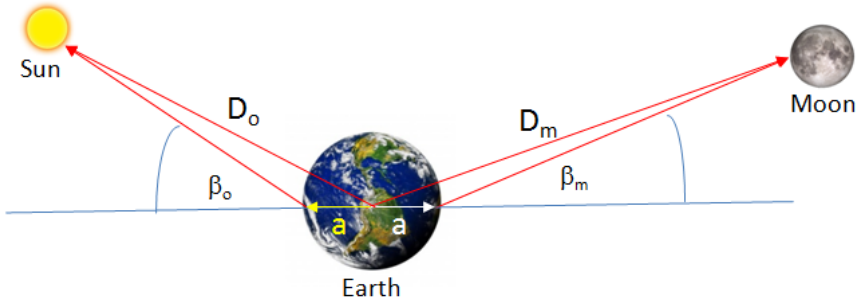
A Java computer program was developed to analyze the pressure data from the Wellington KGS 1-28 to understand the pressure changes, to remove solar & lunar Tidal pressures along with barometric pressure changes. The idea is that if you can remove or explain the natural every day influences you are left with the geological influences and maybe you might be able to identify fluid movement due to brine injection, micro quake swarms, etc. Figure below is an illustration of the raw pressure measurement in psig units over a 4 day period, 30 July to 2 August 2016.



The computer program will filter the noise from the raw pressure data, compute the lunar & solar tidal pressures along with the barometric pressures influence, and then subtract that from the raw pressure data. In an ideal situation if these are the only pressures influencing the pressure measurements then the pressure data should result in a straight line.



A simple square pulse filter is applied to the raw pressure signal to remove the noise in the data. The filter that was settled on for this process was the 1000 pts (1000 seconds). This method removed most of the noise, without removing signals that may be of interest down the line. You can see the lunar and solar cycle in the pressure wave as well as "noise" on top of that signal or is it barometric pressure or something else.



[2]It is well known that the sinusoidal water level variations observed in open wells are directly related to lunar & solar tidal influence. It is also believed that the tidal effects are related to the characteristics of the formation and to the fluid contained in the formation. The lunar & solar attraction of the earth generates a state of stress on the earth's surface which induces a radial deformation of the earth. As the gravitational force of attraction between two masses is inversely proportional to the square of the distance between these two masses, the potential derived from this force will be inversely proportional to the distance between the two masses. In Bredehoeft[1] he attributes to Love[3] (pg 52) that the tide generating potential W may be approximated with sufficient accuracy as a spherical harmonic of second degree,

$$W = 0.5 * (GM_b/D_b)(a/D_b)^2 (3 \cos^2\beta_b - 1) \qquad (1)$$

where
G is the Gravitational Constant = 6.67408×10^{-11} [m3]/{[kg][sec2]}
M_b - Mass of the body
D_b - Distance between earth and body
a - Earth Radius = 6.371×10^6 [m]
β_b - angle between earth and body

References:
1) Response of Well Aquifer Systems to Earth Tides by John D. Bredehoeft, Journal of Geophysical Research, Vol 72, No 12 June 15, 1967.
2) The Earth Tide Effects on Petroleum Reservoirs, Thesis submitted to the Department of Petroleum Engineering of Stanford University by Patricia C. Arditty, May 1978
3) Love, A. E. H., Some Problems o] Geodynamics, 180 pp., Cambridge University Press, Cambridge, 1911, https://archive.org/details/cu31924060184367

Bredehoeft[1] states that the dilatation in an aquifer will depend not only on the tidal strain but also on the effect of change in internal fluid pressure produced by the tidal dilation. The aquifer will be subjected to tidal strains latitudinal and longitudinal directions that are almost entirely determined by the elastic properties of the earth as a whole. Love[3] (pg53) showed that the dilation can be related to the disturbing potential by introducing a fourth Love number, F(r), where

$$\theta = F(r) * (W / g) \qquad (2)$$

Takeuchi[4] evaluated F(r) by numerical calculations indicating that near the earth's surface the dilatation is given by

$$\theta = (0.49 / a) * (W / g) \qquad (3)$$

where a is the earth's radius, g is the acceleration due to gravity (9.8 m/sec2) and W is the lunar & solar tide generating potential. Bredehoeft continues to derive the effects of the dilation as change in pressure of the earth tide in an aquifer system and shows that the earth tide P is,

$$P = \rho g h = \theta / (C_w \phi) \qquad (4)$$

where ρ is the density of the fluid in the borehole, g is the acceleration due to gravity and h is the height of the fluid above the aquifer, ϕ is the porosity of the aquifer, θ is the volumetric strain at the surface of the earth, C_w is the compressibility of the water. The compressibility of the rock itself was neglected because Bredehoeft assumed that the change in rock matrix volume was small compared to that of the water volume.

References:
1) Response of Well Aquifer Systems to Earth Tides by John D. Bredehoeft, Journal of Geophysical Research, Vol 72, No 12 June 15, 1967.
3) Love, A. E. H., Some Problems o] Geodynamics, 180 pp., Cambridge University Press, Cambridge, 1911, https://archive.org/details/cu31924060184367
4) Takeuchi, H., On the earth tide of compressible earth of variable density and elasticity, Trans. Am. Geophys. Union, 31, 651-689, 1950.

The lunar & solar tide generating potential, W_b, equation used in the Java Web App is as follows,

$$W_b = 0.75 * [GM_b/D_b] * [a/D_b]^2 * \{$$
$$(3*\cos(2*\lambda_b) -1) * (3*\cos(2*\lambda_e) -1) /12.0 \quad \text{Long term cycle}$$
$$+ \sin(\lambda_b) * \sin(\lambda_e) * \cos(\omega t - \phi_b - \phi_w + \phi_{corr}) \quad \text{Diurnal ~1 day cycle}$$
$$+ \cos^2(\lambda_b) * \cos^2(\lambda_e) * \cos[2*(\omega t - \phi_b - \phi_w + \phi_{corr})]\} \quad \text{Semi-diurnal ~1/2 day cycle}$$

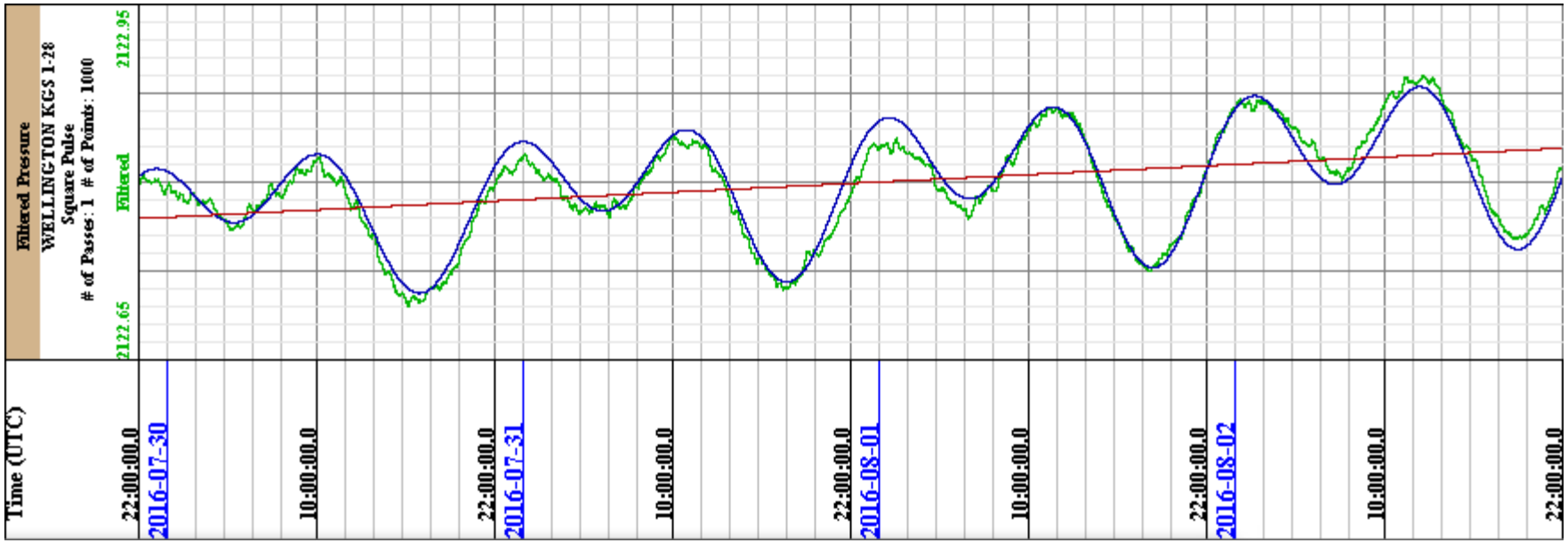
where
G is the Gravitational Constant = 6.67408 X 10^{-11} [m3]/{[kg][sec2]}
M_b - Mass of the body
D_b - Distance between earth and body varying with time
a - Earth Radius = 6.371 X 10^6 [m]
ω - Frequency of the Earth's rotation = 1.1600804 X 10^{-5} [Hz]
λ_e - Latitude of the Wellington KGS 1-28 = 37.3194833 degrees
λ_b - Latitude of the body, which is varying with time, and computed from the degrees above the horizon assuming that 90^o is straight above the location of the Wellington KGS 1-28 latitude, i.e. $\lambda_b = \lambda_e$ * Height above horizon / 90.
ϕ_b - Longitude of the body, which is varying with time, computed from right ascension.
ϕ_w - Longitude of the Wellington KGS 1-28 = -97.433378 degrees
ϕ_{corr} - Correction angle due to the "starting time" of pressure data file.

The total generating potential W is the sum of lunar (W_m) and solar (W_o) potentials, i.e. $W = W_m + W_o$. Substituting the total generating potential W into equation (3) and then into equation (4) gives the pressure due to earth tide as follows,

$$P = (0.49 / a) * (W / g) / (C_w \phi)$$

where in Wellington KGS 1-28 at 5020 feet below the surface in the Arbuckle formation the water temperature is 133.01 ^{o}F from the Temperature Log, log date 3 March 2011 by Halliburton, gives a water compressibility (C_w) of 0.4437 [1/GPa] and the Porosity of the aquifer (ϕ) is about 0.09 [PU].

Pressure Measurement – 30 July to 2 August 2016 UTC



Slope of the Filtered Pressure Wave – Start of file = 2122.77 psi; End of file = 2122.88 psi

Slope of the Filtered Pressure Wave plus Tidal Pressure Wave. { ϕ = 0.09 [PU]; C_w = 0.4437 1/[Gpa]; ϕ_{corr} = -88 [deg] }

Filtered Pressure Data

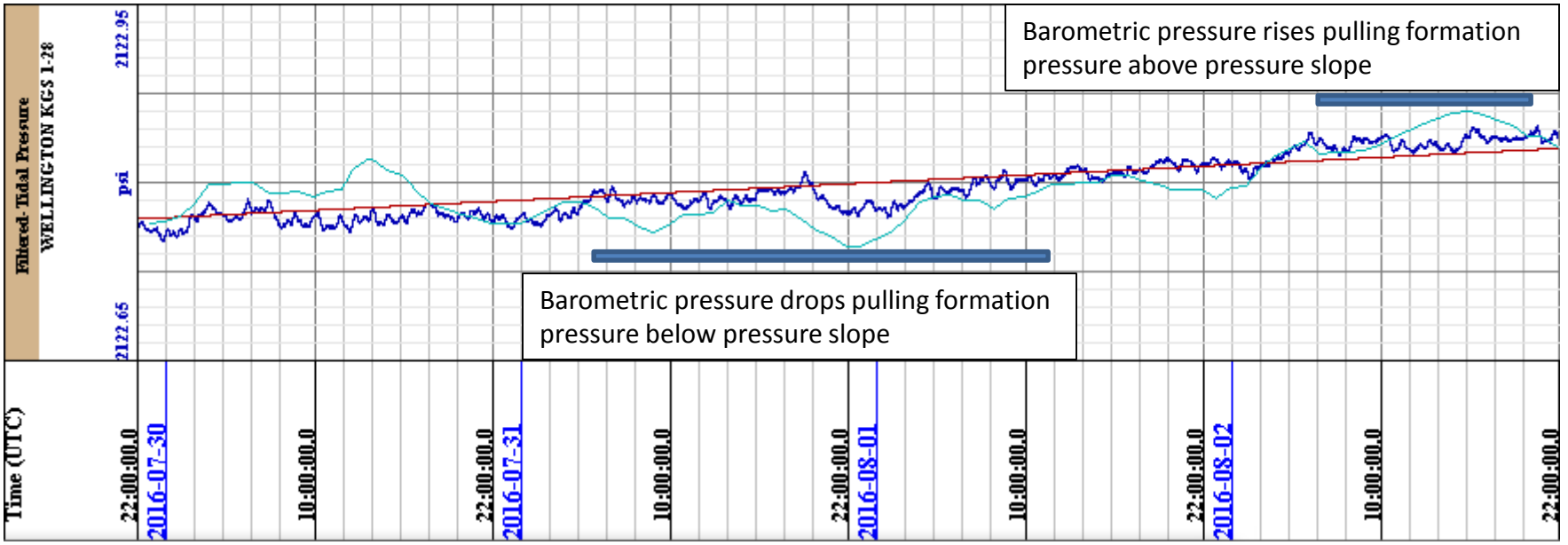
The apparent latitude and apparent longitude of the Moon and Sun is computed from tables[5,6] using linear interpolation between dates supplied, i.e. for the example shown 28 July to 3 August 2016

	Sun			Moon		
UTC (0.0)	Apparent R.A.	° above Horizon	Distance A.U.	Apparent R.A.	° above Horizon	Distance km
7/28/2016,	08 30 50.59,	71.4,	1.015442,	03 12 08.50,	67.0,	369726.0
7/29/2016,	08 34 45.53,	71.2,	1.015337,	04 09 30.01,	69.4,	370288.0
7/30/2016,	08 38 39.89,	70.9,	1.015228,	05 08 00.82,	70.7,	371462.0
7/31/2016,	08 42 33.67,	70.7,	1.015113,	06 07 01.28,	70.8,	373309.0
8/01/2016,	08 46 26.84,	70.4,	1.014992,	07 05 35.56,	69.6,	375854.0
8/02/2016,	08 50 19.42,	70.2,	1.014866,	08 02 46.93,	67.4,	379066.0
8/03/2016,	08 54 11.39,	69.9,	1.014733,	08 57 53.10,	64.4,	382835.0

1.496×10^{11} [m] = 1 Astronomical Unit [AU]

References:
5) Planetary Ephemeris Data for the Sun and Moon http://astropixels.com/ephemeris/ephemeris.html
6) Sun or Moon Altitude/Aximuth Table, Form B – Location Worldwide http://aa.usno.navy.mil/data/docs/AltAz.php

Pressure Measurement – 30 July to 2 August 2016 UTC



- Slope of the Filtered Pressure Wave – Start of file = 2122.77 psi; End of file = 2122.88 psi
- Blue Curve = Filtered Pressure Data minus the Computed Lunar & Solar Pressure Wave
- Cyan Curve = Barometric Pressure + [Pressure Slope – Average Barometric Pressure (14.11 psi)]

A pressure curve is constructed by adding the barometric pressure measured at Strother Field Airport with the difference of the Pressure Slope and 14.11 psi the average ideal barometric pressure at this elevation and overlaying that on the measured data. It can be seen that there is some comparison with the measured data. Ideally if the barometric pressure is measured at Wellington KGS 1-28 then the computed barometric pressure should line up exactly with the linear pressure curve and any deviations from that would be other geological effects, i.e. fluid movement, etc.