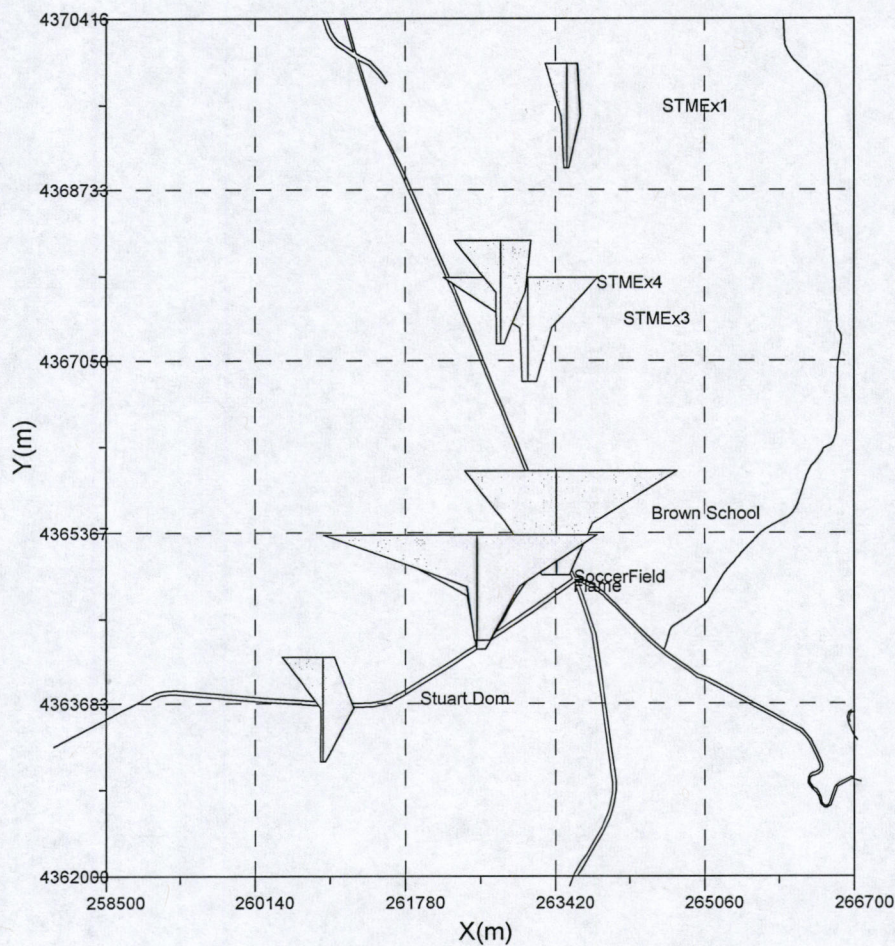


WIDMER

3725-00017

# Piper Diagrams as a media for viewing well chemistry data in the Steamboat Springs Geothermal Area

Spatial association for Na-Cl-HCO<sub>3</sub> water



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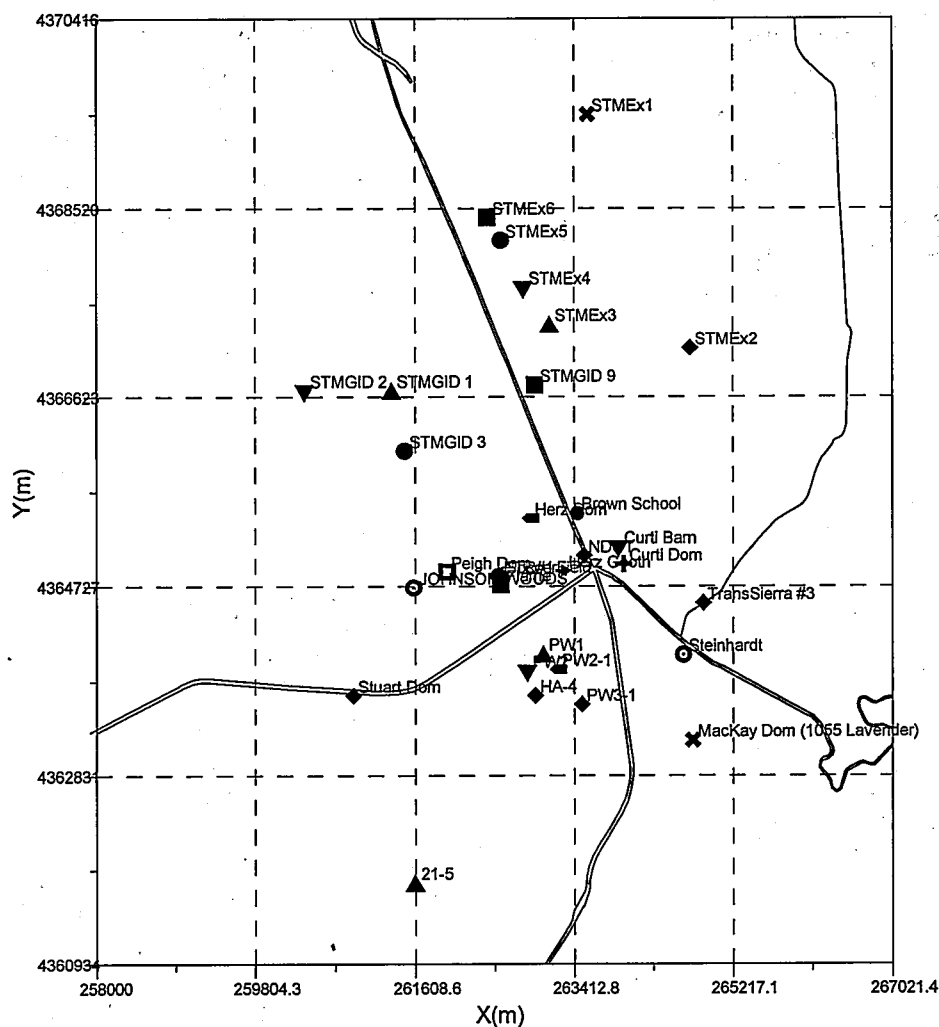
### **Introduction:**

Well monitoring data has been queried to look at the chemistry of the groundwater in and around the Steamboat Springs geothermal area. The idea of looking at individual well sample data chronologically as well as in association with other wells is to address the question of geothermal discharge; is it increasing, decreasing or staying the same? The analytical results are represented in Piper diagrams, Stiff diagrams and time series plots showing concentrations as percentages; in other words the number of milligram equivalents (number of moles of solute x valence of solute species) of solute per kilogram of solution. It is a convenient way for showing the effects of mixing two waters from different sources and allows the reader to view cation and anion compositions of many samples in order to see trends over time. This is depicted in the hydrochemical facies of the Piper diagram, which has identifiable parts of different natures belonging to distinct zones in terms of major ion percentages. Nonetheless, error is introduced by neglecting the effect of ion complexes and activity coefficients.



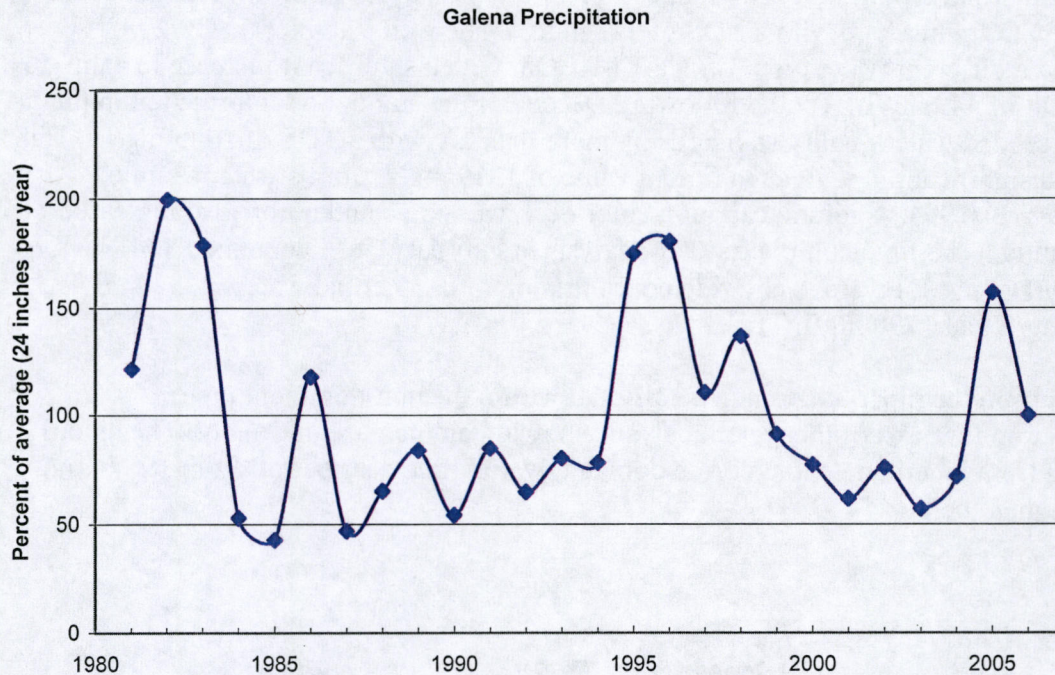
The access database was imported into AquaChem v.4.0 and queried based on three known entities:

- ### Location Map





## 2) annual precipitation record



- 3) geothermal plant start dates  
1984- 1/87 (SBI/IA online)  
1/87- 1/88 (Caithness online)  
1/88- 1/93 (SBII-III online)  
1/93- 1/05 (Cox 1-1 replaced with 64A-32)  
1/05- current

### **Objective:**

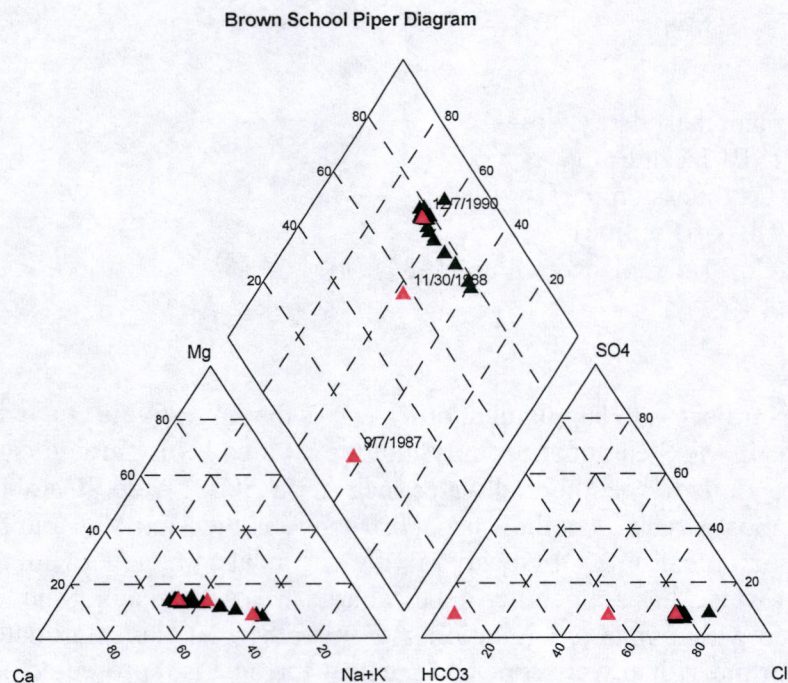
The purpose of this project is to supplement other works that investigate any evidence of changing hydraulics in the Steamboat Springs geothermal area. Normal fault structures are thought to be conduits for geothermal water such as the 500 ft wide Steamboat Fault that parallels Steamboat Creek. Another suspect structure is the Mud Volcano Basin Fault (Widmer, communication). Obviously mixing occurs at some level with two different sources of water; has the geothermal discharge area shifted along the fault zone and is this correlated with annual precipitation and/or geothermal plant start dates? By studying the data for individual wells, one can see how the data is represented on a piper diagram, any changes over time and compare these changes with precipitation records and geothermal plant start dates. Geology combined with drought, cessation of irrigation, municipal pumping and geothermal production wells coming online paints a very complex picture. The following diagrams and their discussions are aimed at illustrating the water analysis data from production and domestic wells in the Steamboat area.



### Brown School

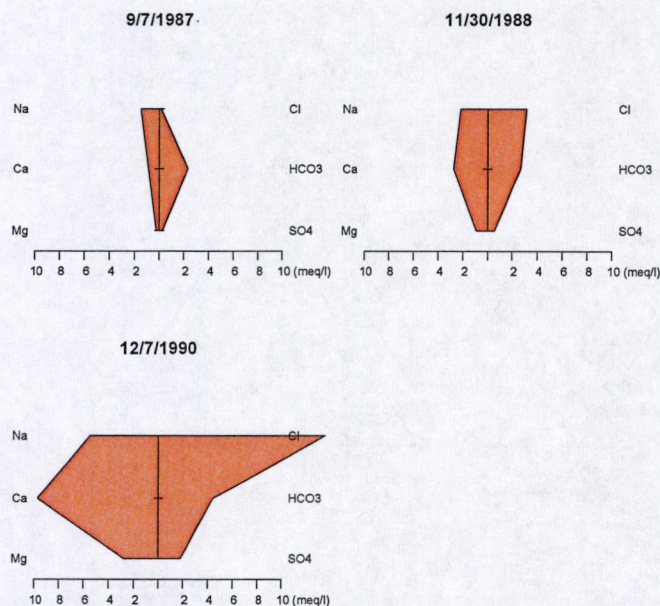
The complete water analysis data for Brown School well spans 10 years. The change in hydrochemical facies suggests a change from low total dissolved solids (TDS) water to more geothermal type water. The first complete water analysis from 9/7/1987, shows a Na-Ca-HCO<sub>3</sub> water type with a TDS of 223 mg/L. The well, sampled 11/30/1988, contained a different water type: Ca-Na-Cl-HCO<sub>3</sub>, with a significant increase in chloride and a TDS of 449 mg/L. By the following December the amount of chloride ion in the water exceeded water quality standards by more than 2X with a TDS of 1045 mg/L. TDS increased significantly, with a maximum value of 1919 mg/L from a water sample collected 5/11/1994. Sodium, calcium, chloride, bicarbonate and boron also increased significantly. The final complete water analysis in February 1997, contained 334 Na mg/L, 690 Cl mg/L (average chloride concentration of geothermal waters is 820 mg/L), 39.5 B mg/L and 1790 mg/L TDS.

The cations in the piper diagram generally fall within the non-dominant type classification for most of the water analysis; showing an increase in Ca ion. The anions migrated from bicarbonate to chloride domain, over a three year period from 1987-1990, as highlighted below.





This is the major change in Brown School well. Considering stiff diagrams of the three samples allows one to view the ionic change, with notable increases in Na, Ca, Mg, Cl and SO<sub>4</sub>.

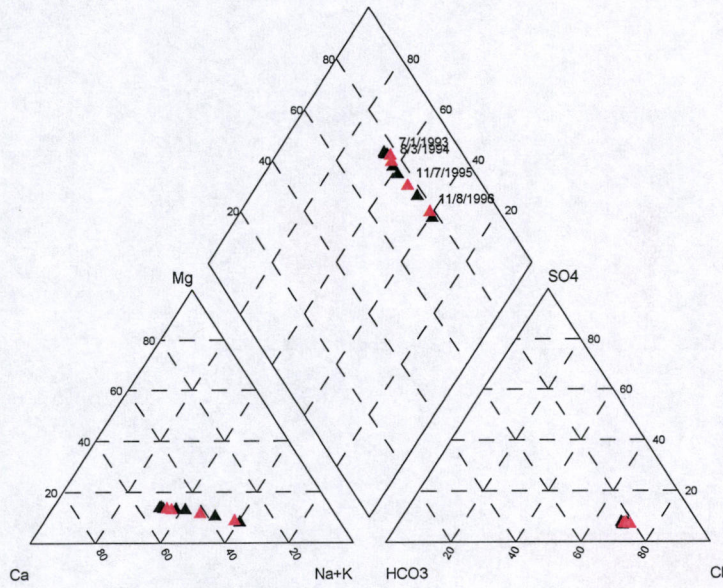


Following this change in chemistry, approximately two-dozen water analysis samples were taken during the calendar years of 1991 and 1992. The data shows a steady increase in TDS. There were no monthly fluctuations correlated to the seasons during this two year period and the record of below average annual precipitation showed no direct relations.

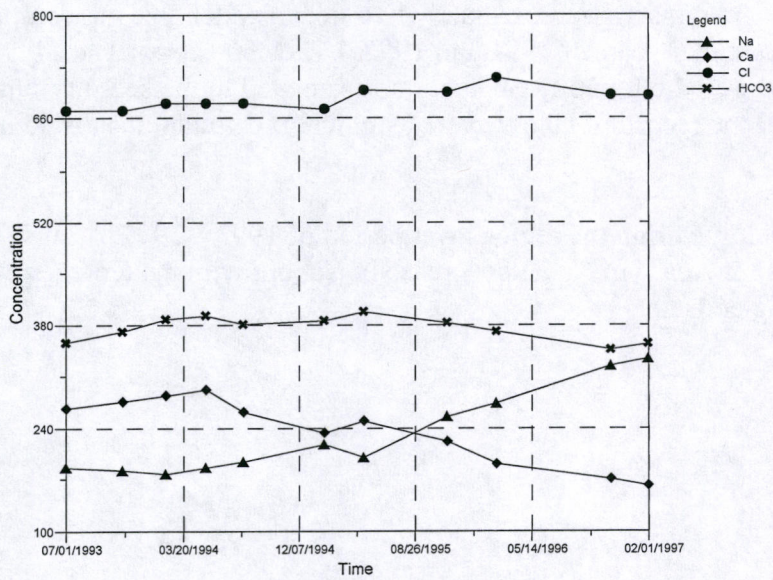
The change observed below during the regions wet period of 1993 – 1997, occurs between cations, with an increase in Na and decrease in Ca ion, with percentages of HCO<sub>3</sub> and Cl remaining constant.



Brown School 1993 - 1997



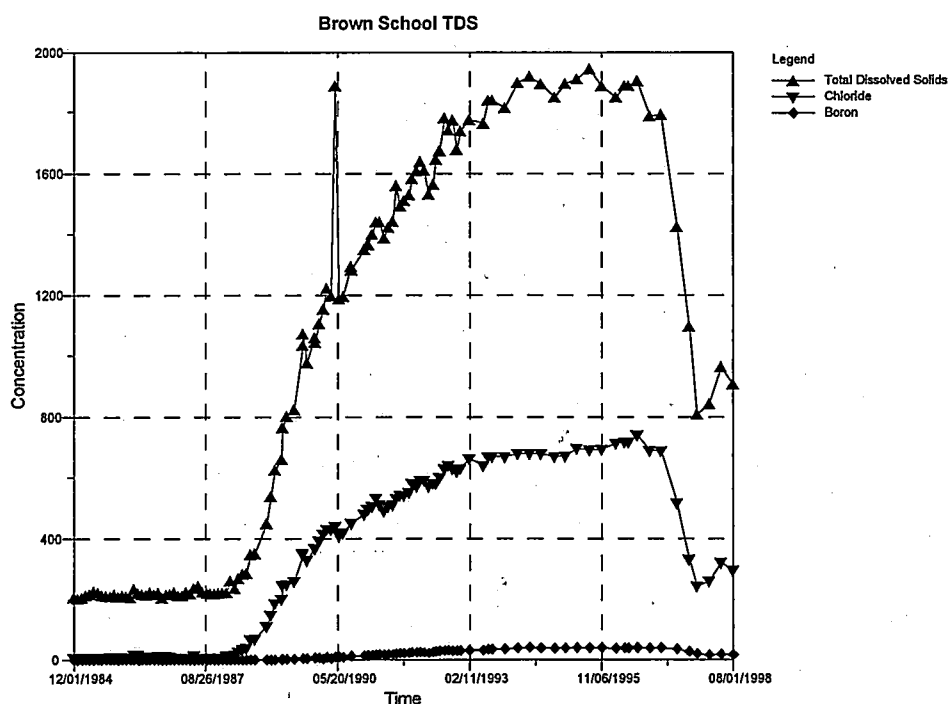
Time Series Plot





The above time series plot and piper diagram do not show an expected increase in  $\text{HCO}_3^-$ /decrease in  $\text{Cl}^-$ , which might be seen if the processes governing the hydrochemistry of this well were solely related to surface recharge and precipitation.

Considering the overall TDS and conservative ion percentages of  $\text{Cl}^-$  and B, a correlation with precipitation can be drawn. The general trend shows an increase of concentrations through the dry years and into the wet period between 1995 and 1997, and then in November 1997 there is a drop in TDS,  $\text{Cl}^-$  and B:



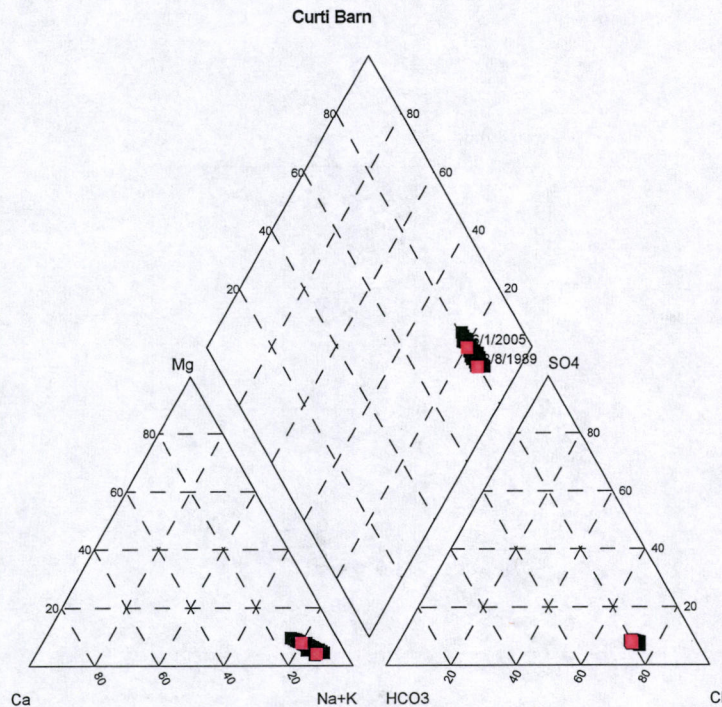
It is possible this trend depicts a lag time between increased concentration of ions and surface water recharge into the groundwater aquifer. Annual precipitation was normal from 1984 through 1987.

Adding complexity is the fact that irrigated acres in 1987, were 65 percent less than in 1984 for the area between Zolezzi Lane, U.S. 395 and Hwy 431 (Widmer, 2006). Data collection ended on 8/1/1998, any further decrease/increase in the trend is unknown and another below average precipitation period began in 2000, which may or may not have affected the well water.



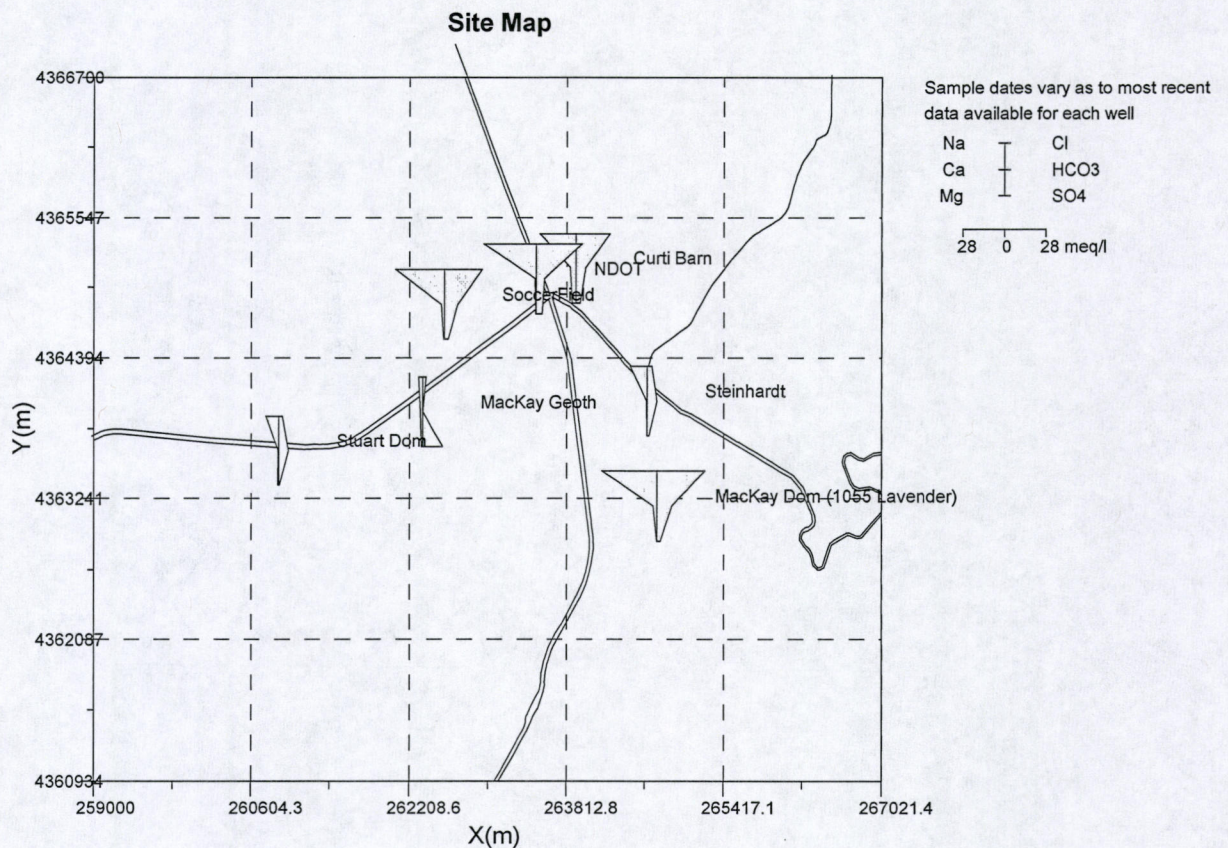
## Curti Barn

The Curti Barn water analysis has changed little since 1987; it continues to show nearly pure Na-Cl water into 2005.



The following map spatially shows the Curti Barn well along with a few other Na-Cl type waters outside of the geothermal production zone (SW of U.S. 395, Hwy 431 intersection). Note the east-west trend of Steinhardt, Mackay geothermal and Stuart domestic: the sample dates varied, however their most recent data indicates a Na-HCO<sub>3</sub>-Cl type water (except Mackay geothermal is Na-SO<sub>4</sub>-Cl), and all three wells have a lower TDS, expressing itself as a lower meq/L value on the Stiff plots, than the surrounding wells to the north and south.



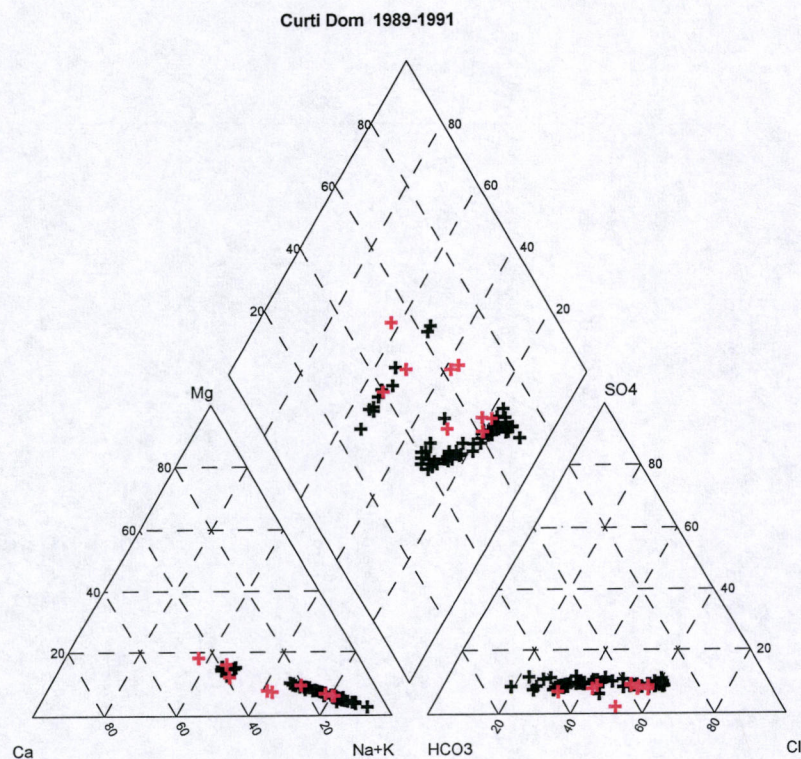


### Curti Domestic

The Curti Domestic well has water analysis data spanning 20 years (1987- 2007). Initial testing from 1987 through early 1989 showed a high percentage of Na-Ca bicarbonate ions. A water sample taken Jan 01, 1990, had significant increases in Na and Cl ions, changing the water type to Na-Ca-Cl-HCO<sub>3</sub> (based on percentages). Over the ensuing 15 months, analysis showed a yo-yo affect with milliequivalents per liter of Na and Cl ions decreasing then increasing to levels exceeding water quality standards (as seen in two samples taken 3/1/1991 and 3/7/1991): sampling technique may be a concern.

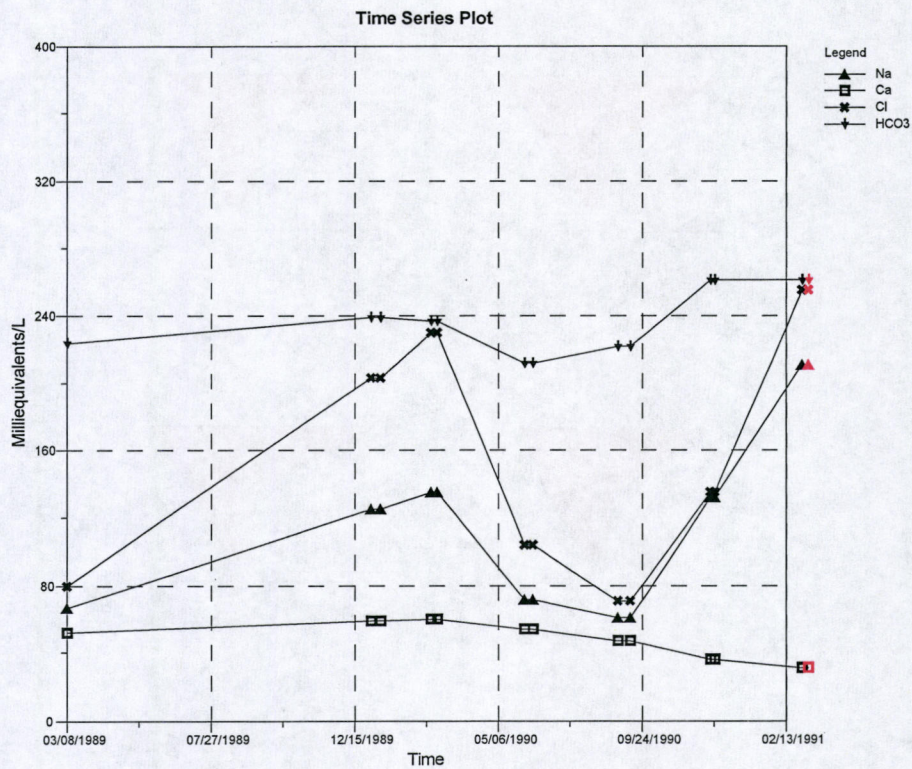
(MW- sampling of various wells occurred with dates unknown and a new well was hooked up in the 1990s. Get data from Bruce MacKay on this source transfer)





The above highlighted data shows a unique history tied to its hydrochemical facies shift; in the last half of 1990, a new well was constructed and used for the Curti domestic source. The well is located 1,200 feet to the southeast from the previous wells. Chronologically, this piper diagram shows a shift from left to right of increasing Na-Cl ions over three calendar years. From 6/1/1990 to 9/13/1990 the cation and anion composition of the water returned to pre-1989 levels, however, by December of 1990 Na and Cl ion levels were increasing again and spiked to unsafe levels by March of the following year.

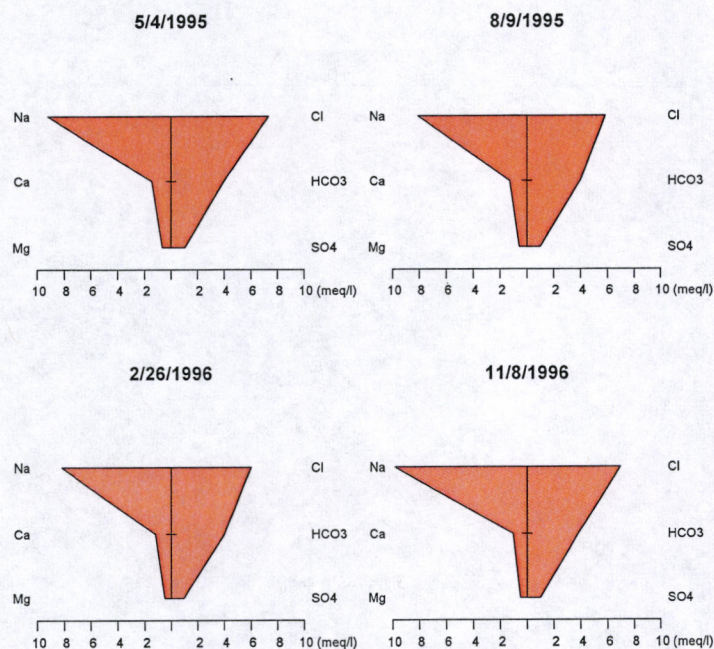




The time series plot, expanded for 1989 –1991, depicts the fluctuation in Na-Cl ions, possibly reflecting some level of fresh and geothermal water mixing together.

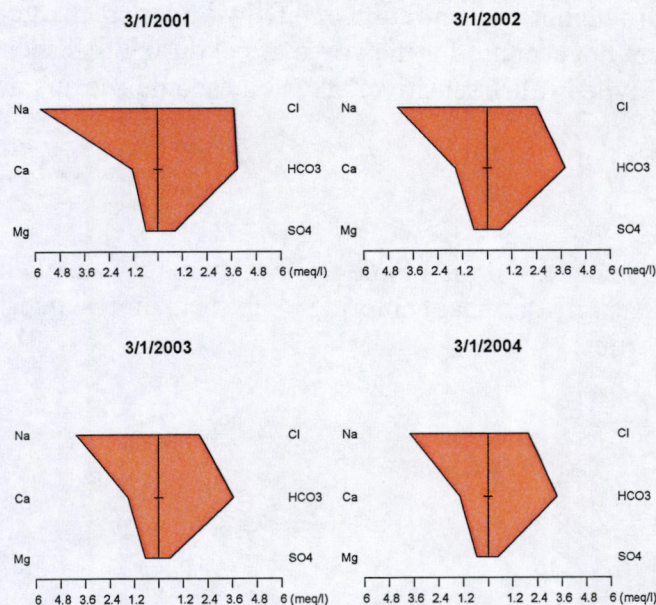
Another way to look at the data is through a stiff diagram series. The shapes depict the ions and their proportion to each other in solution; allowing change in relation to all considered ions to be seen. In 1995, the first wet year following a dry period, there is a potential correlation with groundwater recharge, a slight decrease in Na-Cl ions. They still dominate the water type though:





HCO<sub>3</sub> increases accompanied by a decrease in Na-Cl from May 1995 through February 1996, then during the summer and fall of 1996 show an increase in Na-Cl with a decrease in HCO<sub>3</sub>. However, looking at the following sample data, one would expect an increase in Na-Cl due to a drought lasting from 2000-2005 within the region. The Stiff diagrams below show the opposite.





Na, K, Cl, SO<sub>4</sub>, HCO<sub>3</sub> and F uniformly decrease over these four years, with Ca and Mg averaging no change over the time span. Therefore, one cannot conclude that there is truly any one process affecting the hydrochemistry of this well. In assessing what may be causing these changes one should consider:

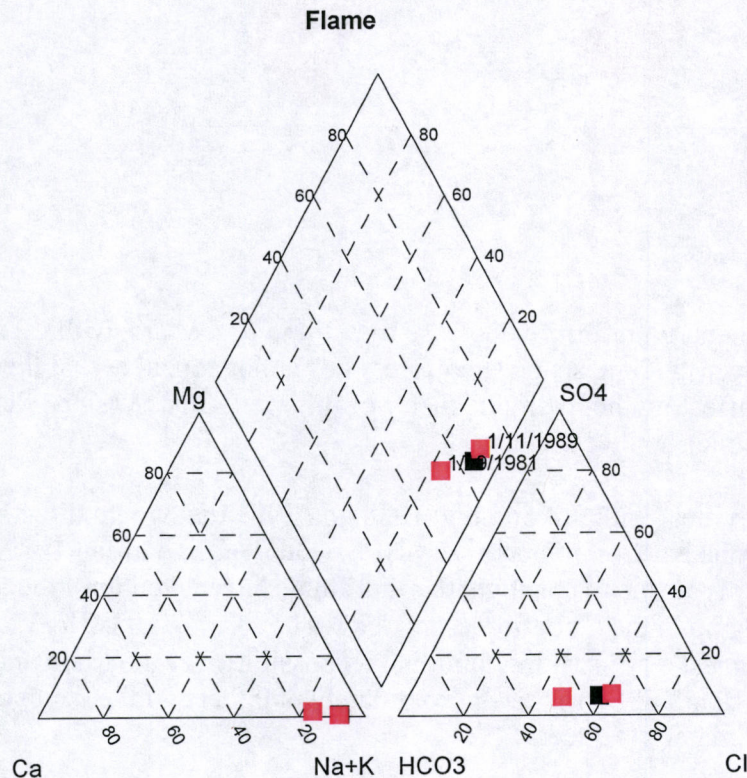
- (1) geothermal activities (with nothing b/w 1988 and 1993 that would directly be responsible for the Na-Cl ion increase): SBI/IA came on-line in Jan 1987, could a change in water type due to spent geothermal fluids have taken until the later half of 1989 to show up in the Curti domestic well? The location of SBI/IA and Curti Dom would suggest a NE striking fault, is this possible over the Main and Low Terraces? The depth of SBI/IA is approximately 600 feet and the depth of Curti Dom is approximately 150 feet.
- (2) Consideration should be given to what has been proposed as a stable geothermal zone located across Steamboat Creek, the area surrounding the Curti Barn well (Yeaman, 2006). Steamboat Creek flows along a normal fault zone approx. 500 feet wide, through alluvium and hot-spring deposits. Could the mixing of alluvial and geothermal waters be due to a lowering of the shallow groundwater aquifer and mixing with geothermal water? As the cooler fresh water volume decreases, the more buoyant hot water rises possibly to the elevation matching the depth of the well.



- (3) The late 80's, early 90's were drought years, with annual precipitation below average. Groundwater recharge would have been low between 1989 and 1991. It is assumed hydrochemical facies of the aquifer correlates with interactions with the country rock (a higher concentration of TDS with less recharge), therefore, recharge alone can not account for the yo-yo affect during this short dry time span (unless the water type is ultra sensitive...then one should see an annual fluctuation).

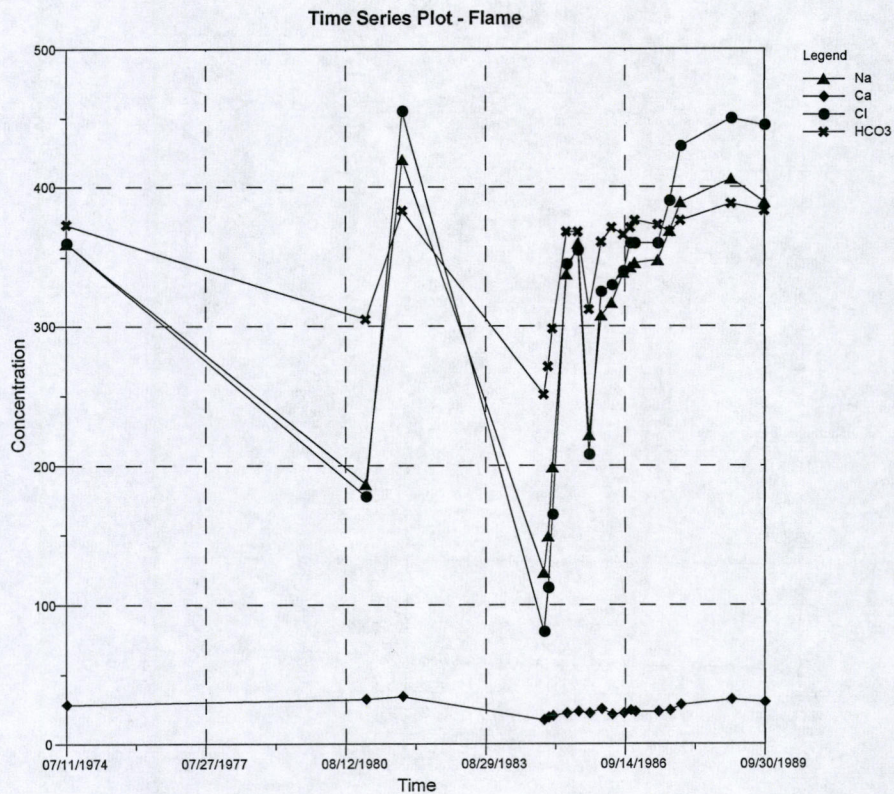
### Flame

The cation and anion percentages for the Flame well water analysis show dominant sodium facies. The increasingly dominant chloride ionic speciation suggests change toward geothermal properties.



Water analysis spans from 1974 through 1989, throughout the first eight years, sample collection was sparse. A time series plot shows no clear trend during the 15 years of data collection.

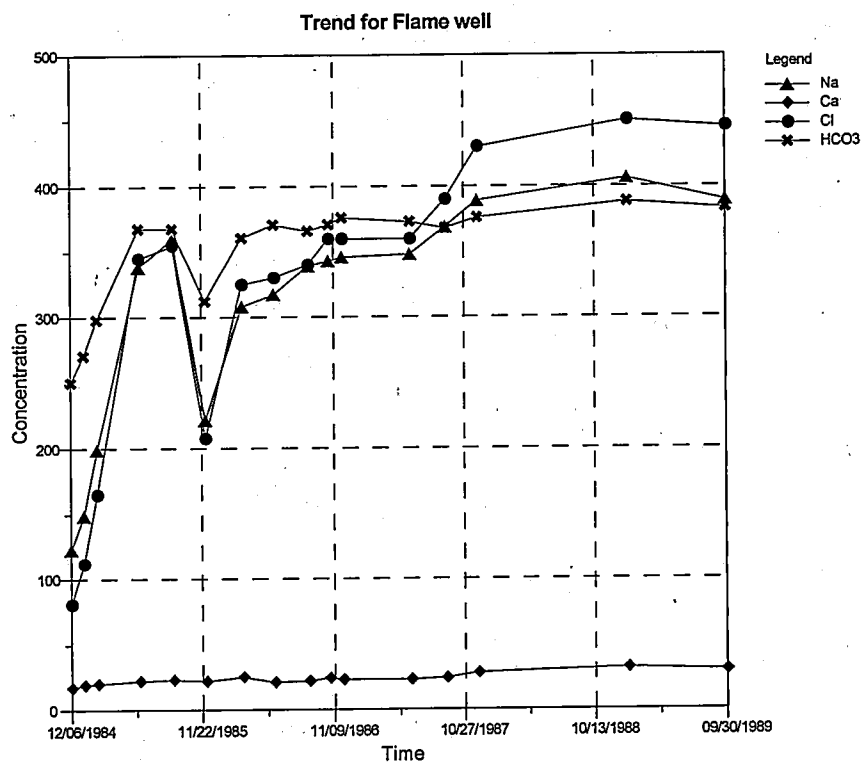




The fluctuation in ions may be due to the location of the well and its susceptibility to irrigation influence. The hydrochemical facies appears to be correlated with fresh water recharge possibly from ephemeral drainage and minor flooding.

By overlooking the first ten years of sampling and expanding the final five years of data there is an indication of mixing water. During this time Na-Cl increased while little change occurred for the percentages of HCO<sub>3</sub> and Ca ions.

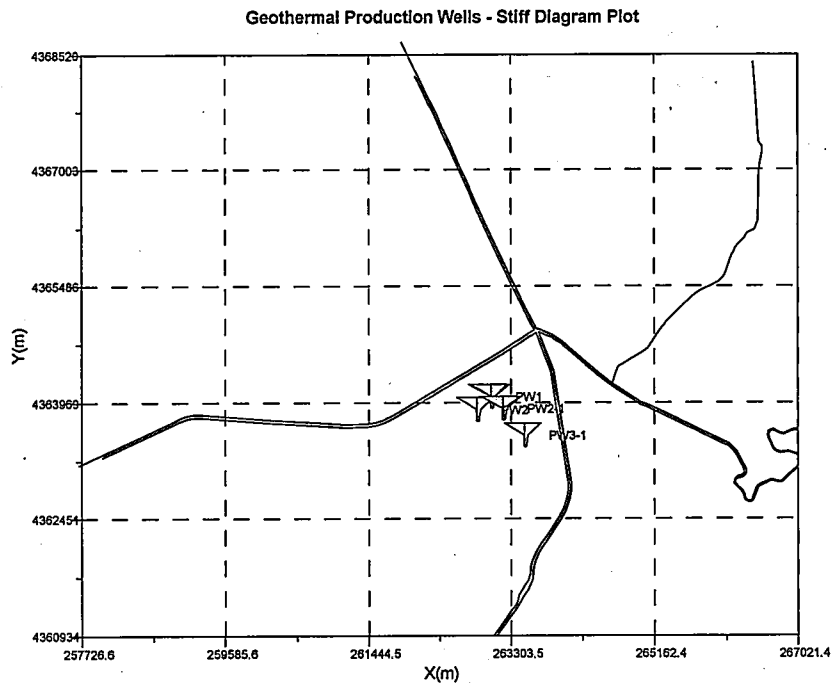




An explanation for this could be related to the location of the Flame well in the Mud Volcano fault zone, and a mixing of fresh and geothermal water.



## Geothermal Production Wells



These four wells are associated spatially and vary little in chemistry, obviously tapping the same geothermal source.

### PW2-1

The geothermal well, PW2-1, is located on the lower steamboat terrace and chemically is near pure sodium chloride type water. The well depth is 990 ft.

### PW3-1

The geothermal well, PW3-1, contains sodium and chloride as its major ion constituents. Well depth is approximately 750 ft.

### PW1

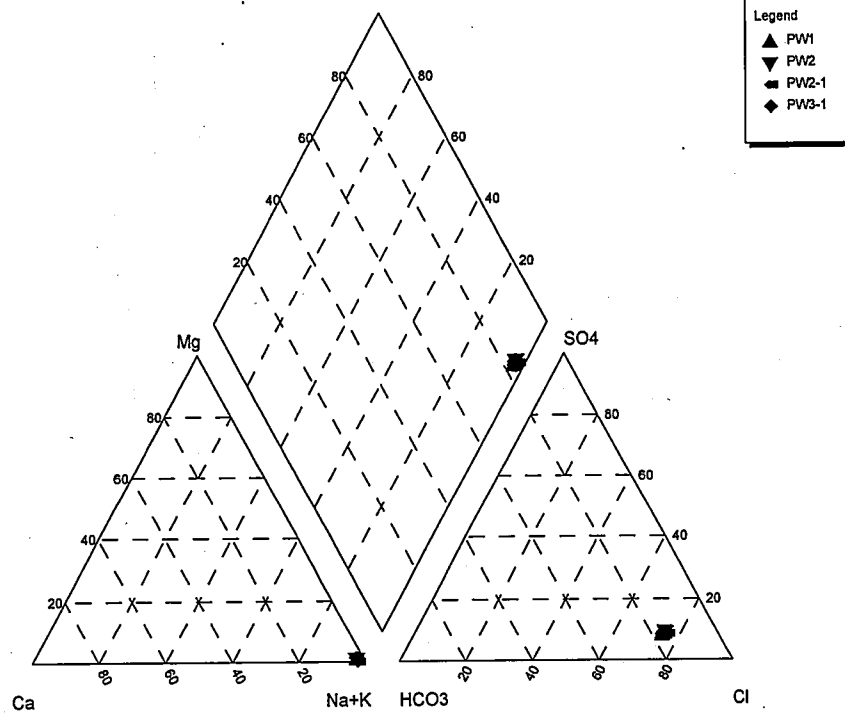
Geothermal production well 1 is Na-Cl water. Well depth is 630 feet.

### PW2

Geothermal production well 2 contains Na-Cl water. The well depth is 530 ft.



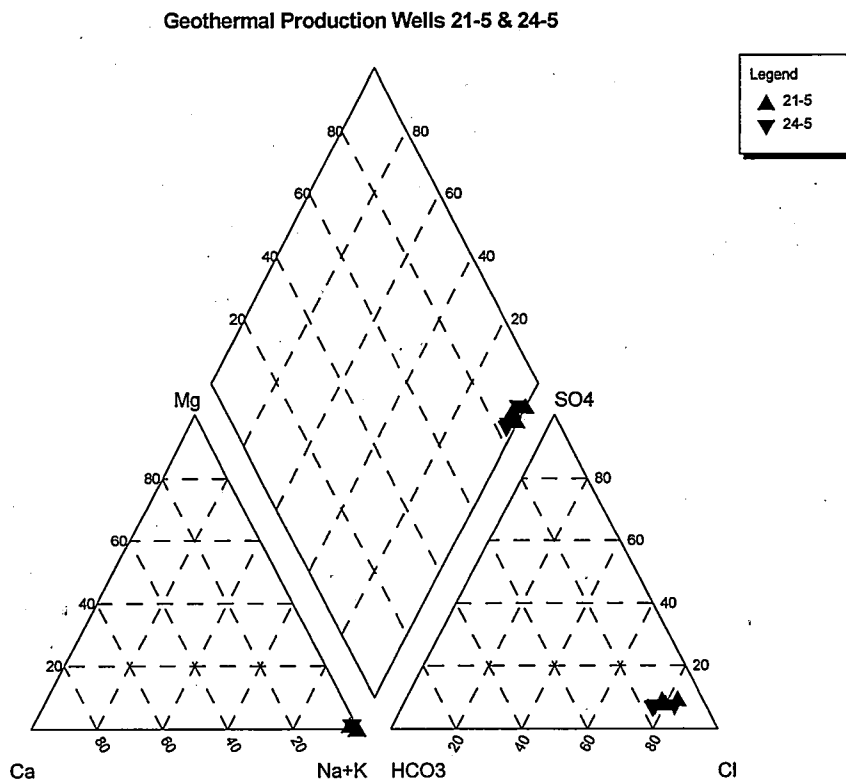
Piper Diagram for Geothermal Production Wells



The four wells plot in the same compositional category on the hydrochemical facies.



Both 24-5 and 21-5 are located on the shoulder of Steamboat Hills range.  
21-5 has a well depth over 2800 feet. 24-5 has a well depth over 2500 feet.

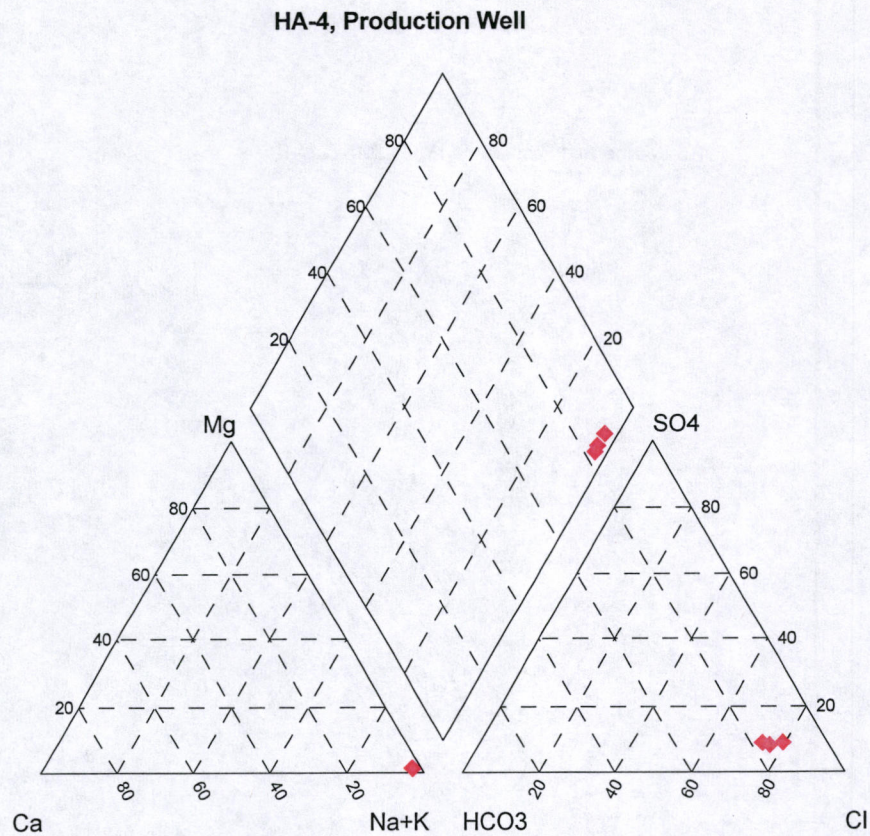


The chemistry is very similar between the two wells and between all six geothermal production wells.

#### HA-4

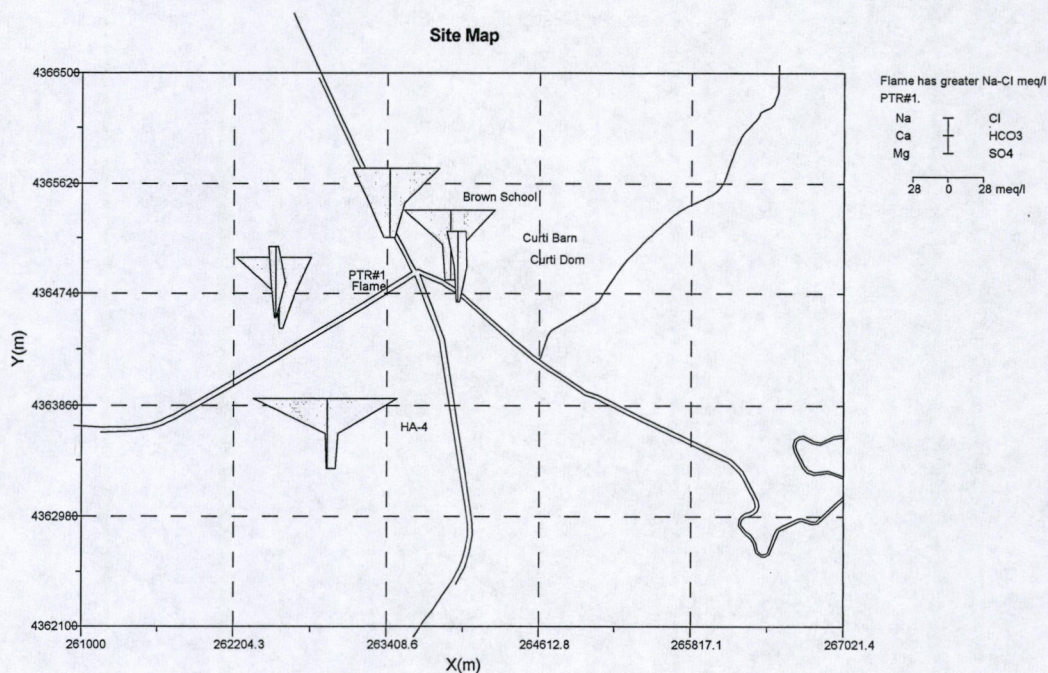
HA-4 geothermal production well has a depth of 729 ft and was completed in early 1990. The piper diagram shows geothermal water.





Data has been collected from 9/1998 through 6/2006. Looking at spatial relations between HA-4 and other select wells, on the map below, show an elementary NE trend between Stiff diagrams for HA-4 and Curti Barn wells.





With the most recent data available, water analysis for Curti Barn is dated 3/2005. The sample date for HA-4 is 6/2006.

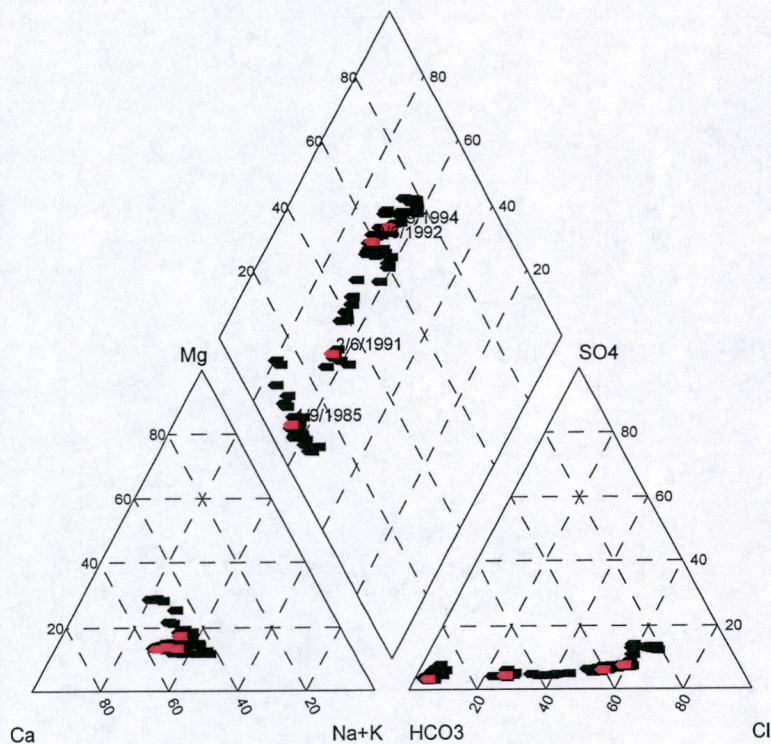
As a side note, one may discern an east-west trend between PTR#1 and Curti domestic wells (both sample dates from 1989), of significantly lower TDS than nearby wells. The large spread in sample dates on this map may make a direct comparison between wells invalid, however working with available data it is interesting to note any trends, either parallel or continuous, for future reference.

### Herz Domestic

The broadest changes in the Herz domestic water chemistry have occurred with its anion constituents. The cations have remained in the Ca+Mg, Na+K zone for 23 years, displaying that there is no dominant cation specie. The anions, however, have shifted back and forth through time from bicarbonate/carbonate type to chloride type water.



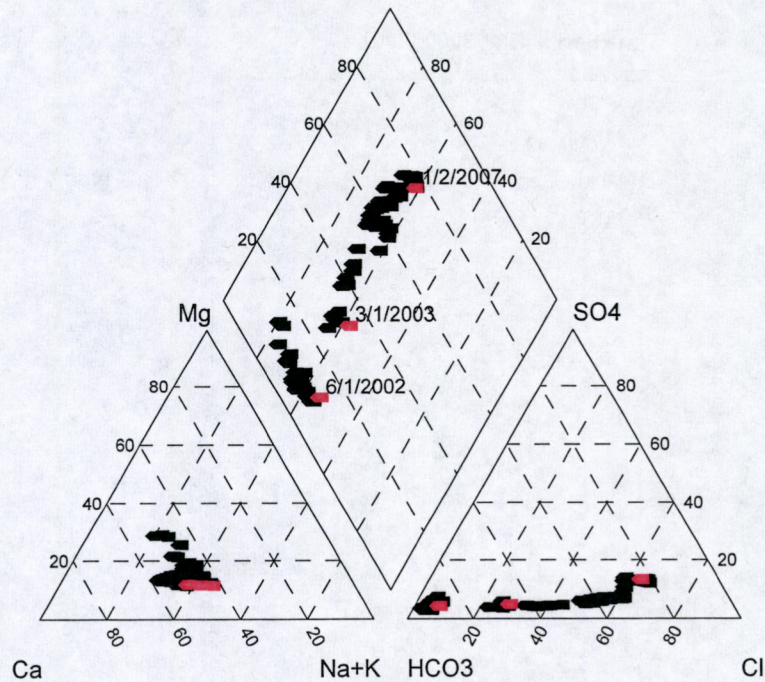
# Herz Domestic - Early 90's Ion Shift



This well has a depth of 112 feet. In the 1960's the water level was at 56 ft. (White et. al., 1964). Water level today is 56 feet. Hydrothermal clay has been found at 50 – 130 feet, this may be a source of Na and Cl and a contributor to the increased TDS during dry periods. The year groupings containing large spreads are from 1988-1993 and 2002-2007, which may be tied to annual precipitation rates. A closer look at these two groupings follows.

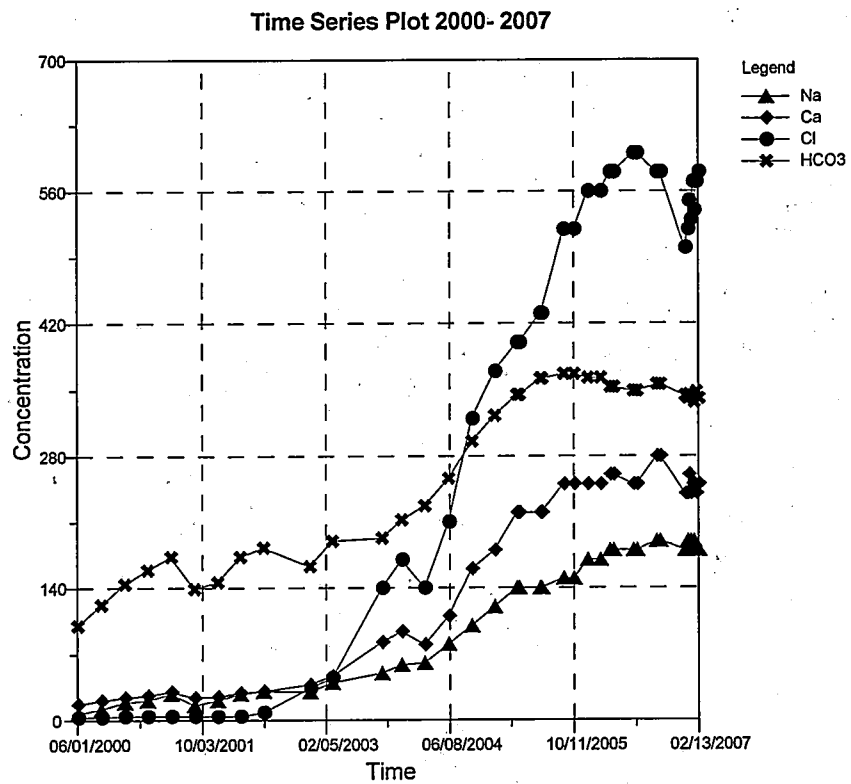


### Herz Domestic - Recent Chemical Shift



The above piper diagram depicts a shift in anion percentages from predominately  $\text{HCO}_3$  to  $\text{Cl}$ , while the cations remained unchanged. The time series plot, below, shows the fluctuation in dominant anion speciation over recent years of sampling. Viewed with annual precipitation records, there appears to be a correlation between dry/wet years and bicarbonate ions in the Herz domestic well. Calcium and sodium ions appear to be following a similar trajectory.

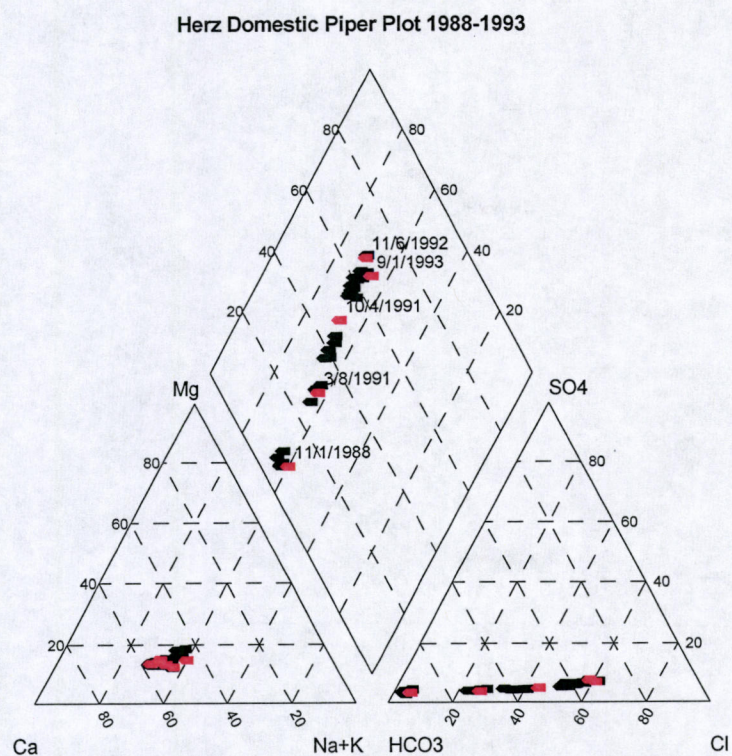




Chloride ions suggest some other effect on water chemistry, their percents sharply increased from 2003 through 2005. An explanation could range from anthropogenic (sample collection technique) to geothermal mixing of water types.



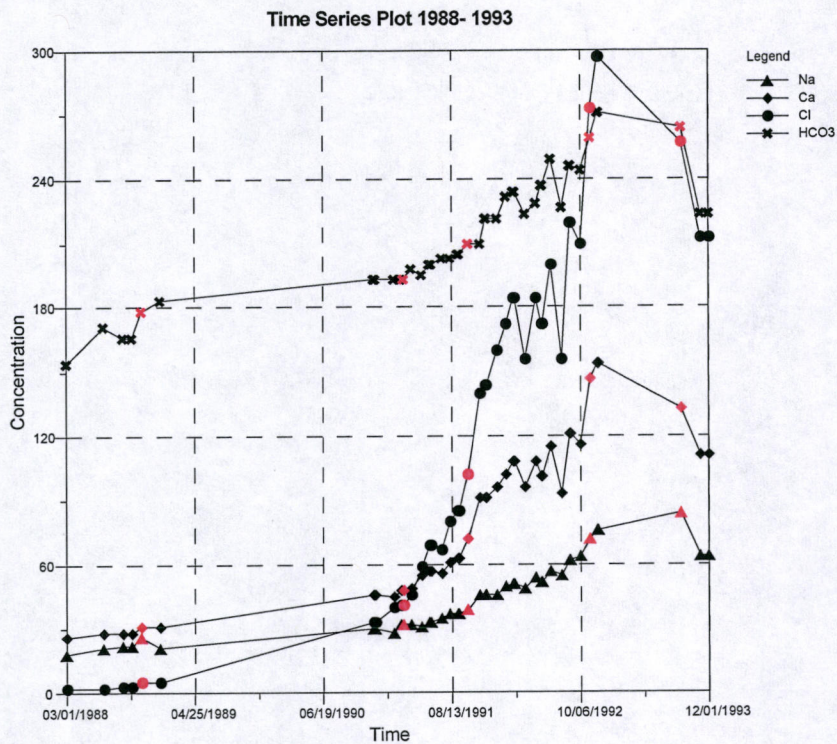
Looking back at the major change in hydrochemical facies during 1988 – 1993, we can see a similar shift in anions, from HCO<sub>3</sub> toward Cl type water.



Chronologically, the anionic shift is moving left to right.



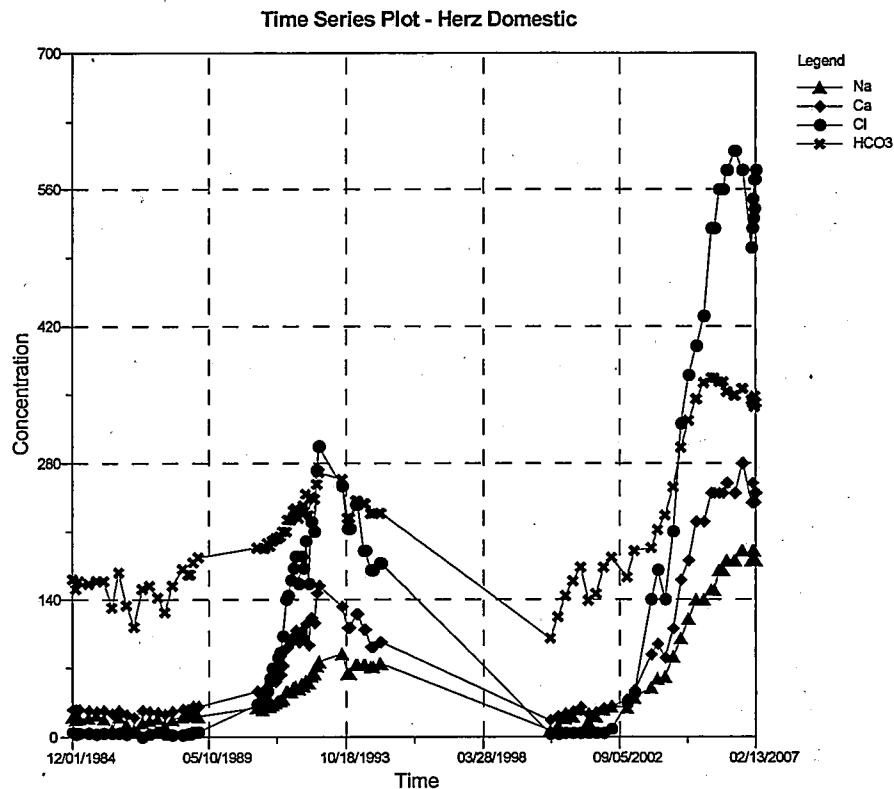
The time series plot for this period depicts a correlation between annual precipitation and HCO<sub>3</sub>-Cl fluctuation. Chloride ion peaks at the end of 1992, followed by switch in dominant anion in 1993, which was a wetter year.



The ions appear to have followed suit with precipitation on the extreme right-hand side of the plot, however, between 1991 and 1992, all considered ions are increasing in concentration. This may be a factor of mixing alluvial and geothermal waters.



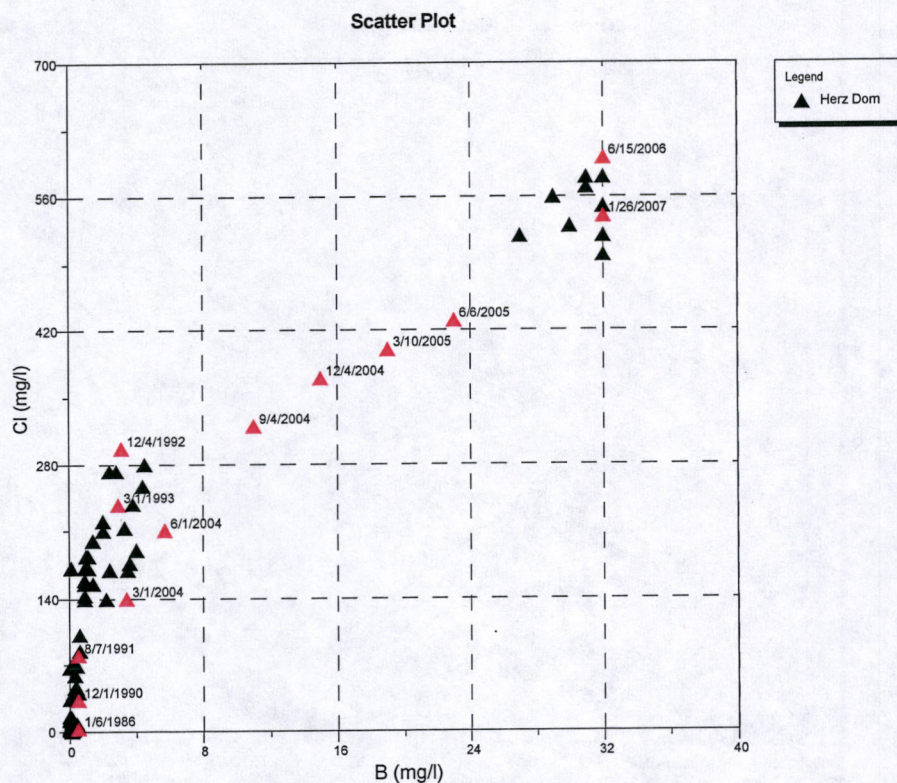
There is a break in data between 1994 and 2000, where  $\text{HCO}_3$  recovered and the weight percent of Cl decreased dramatically, as seen in the overall time series plot below.



Extrapolating from the annual precipitation log, it may be hypothesized that the wet years from 1995 through 1999 helped ions recover to 1984 conditions by possibly raising the aquifer's water level, however there is no evidence included in this report of increased aquifer water levels.



Considering Boron: B-Cl are conservative solutes and when present are evidence for mixing of geothermal and non-thermal water.



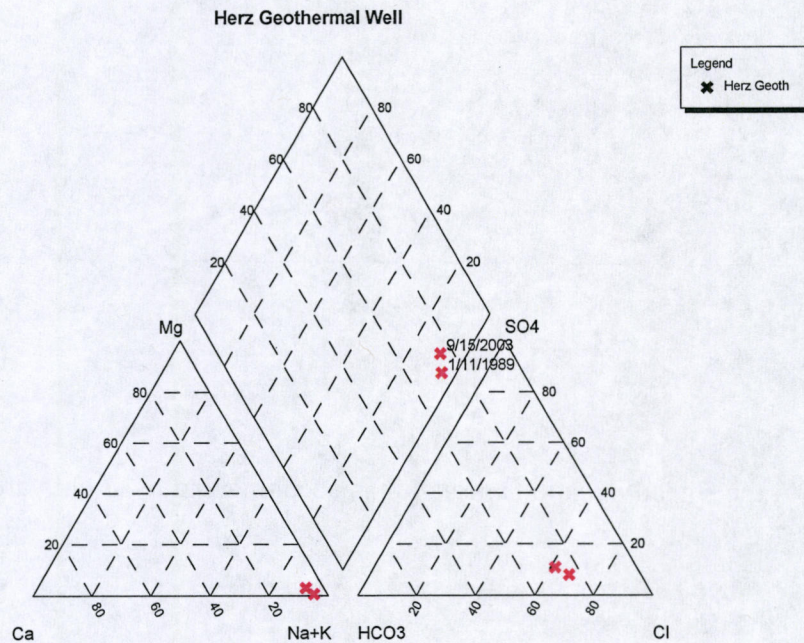
Even with fluctuations in Cl ion percentages seen above, the trend when chloride is plotted against boron is towards thermal water.

Hence, with a decrease in fresh water due to drought, the cap on the geothermal water may have decreased and a mixing of the two water types may be what is observed in the piper diagram and time series plots.



### Herz Geothermal

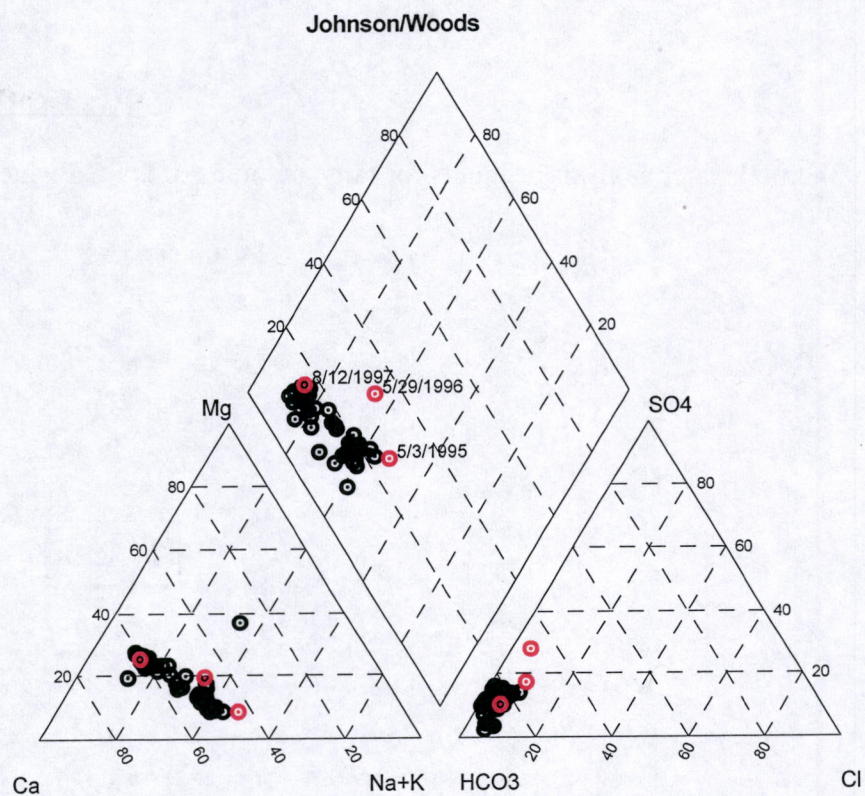
The Herz geothermal water analysis accounts for large amounts of Na-Cl, which has not changed over time.



### Johnson/Woods

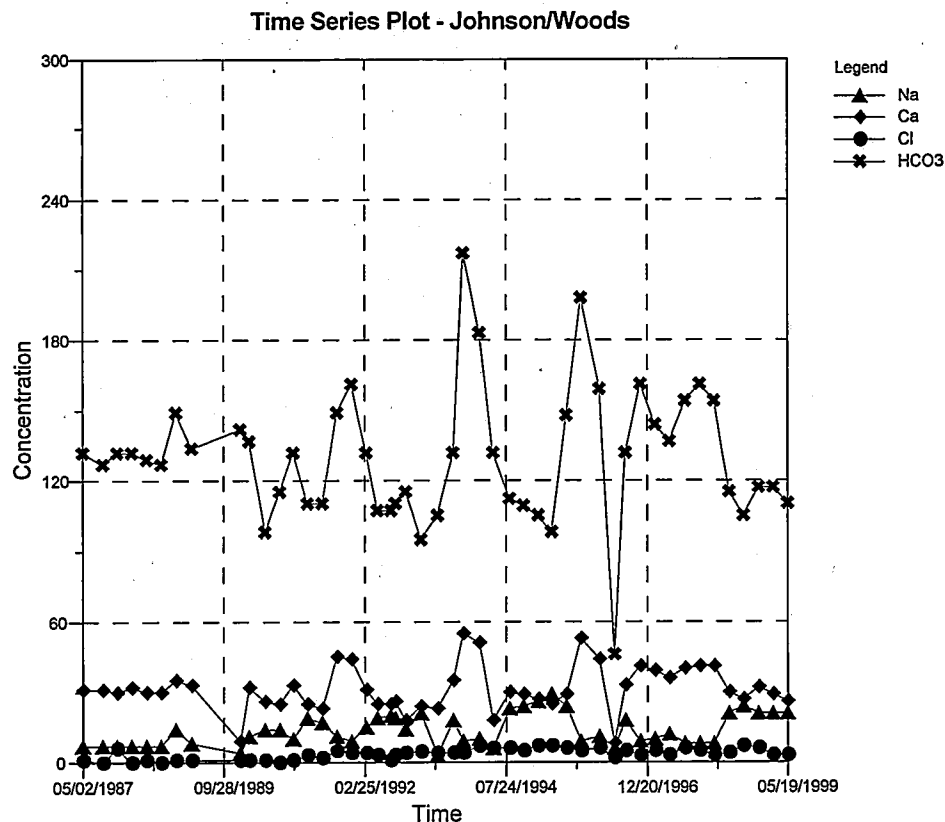
Johnson/Woods domestic well has complete water analysis data for approximately 10 years. The piper diagram shows relatively small variations over time, in the predominately alkaline bicarbonate type water. The broadest change occurred between cations, primarily Ca, during the late 1990's.





Between 1995-1997, the spread in cation speciation is accompanied by slight variations in  $\text{HCO}_3$ .

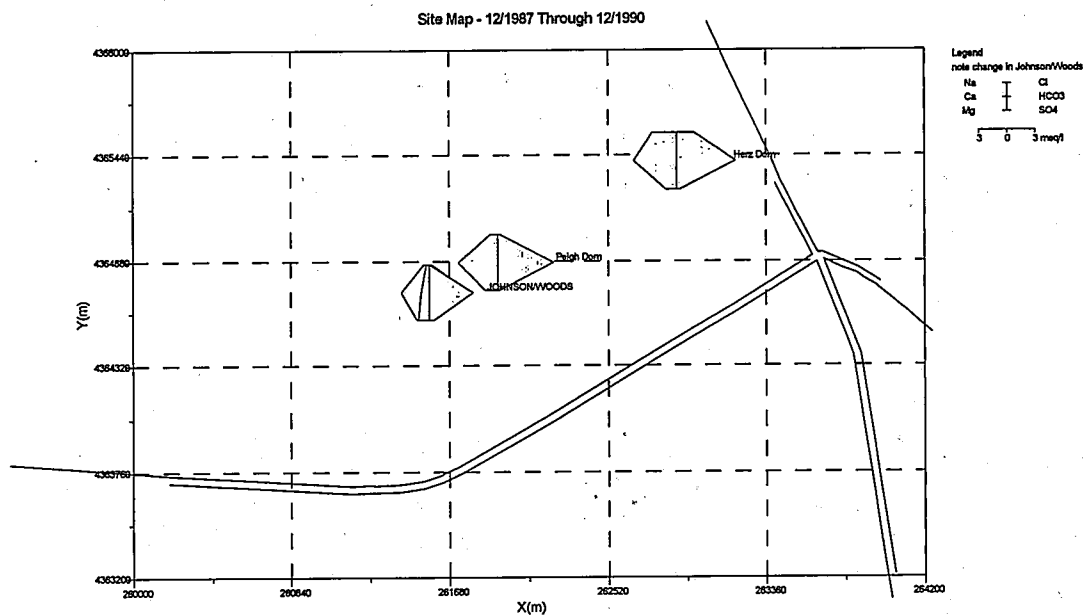




Comparing the Time Series plot to annual precipitation, there may or may not be a correlation between the ion speciation and recharge from rainfall. One would expect HCO<sub>3</sub> levels to be low in the late 1980's escalating during 1993 – 1995 (responding to a change from a dry to wet period), to sustained higher levels through the late 1990's. This bicarbonate increase is not clearly observed on the time series plot. Another source causing a fluctuation in HCO<sub>3</sub> could be a result of infiltrating fresh water from Steamboat Ditch and Whites Creek into the aquifer. The large dip in early 1996 is not explained, except for possible anthropogenic reasons in sample collection technique. The rise and fall is clearly seen in both Ca and HCO<sub>3</sub> trajectories; note Ca and Na are mirroring each other as the primary cation while Cl remains at low percentages. The processes at work on the hydrochemistry in Johnson/Woods appear to be related to ground water recharge.



The following map shows stiff diagrams of Johnson/Woods, Peigh and Herz domestic wells over a dry period of time. The changes seen in these three wells from 1987 – 2000 are indicative of the spatial locations being affected by ground water recharge accompanied by mixing of fresh and geothermal water in the Herz domestic vicinity.



An observed change occurred in Johnson/Woods, with an increase in Ca ion, between 1987 and 1990.

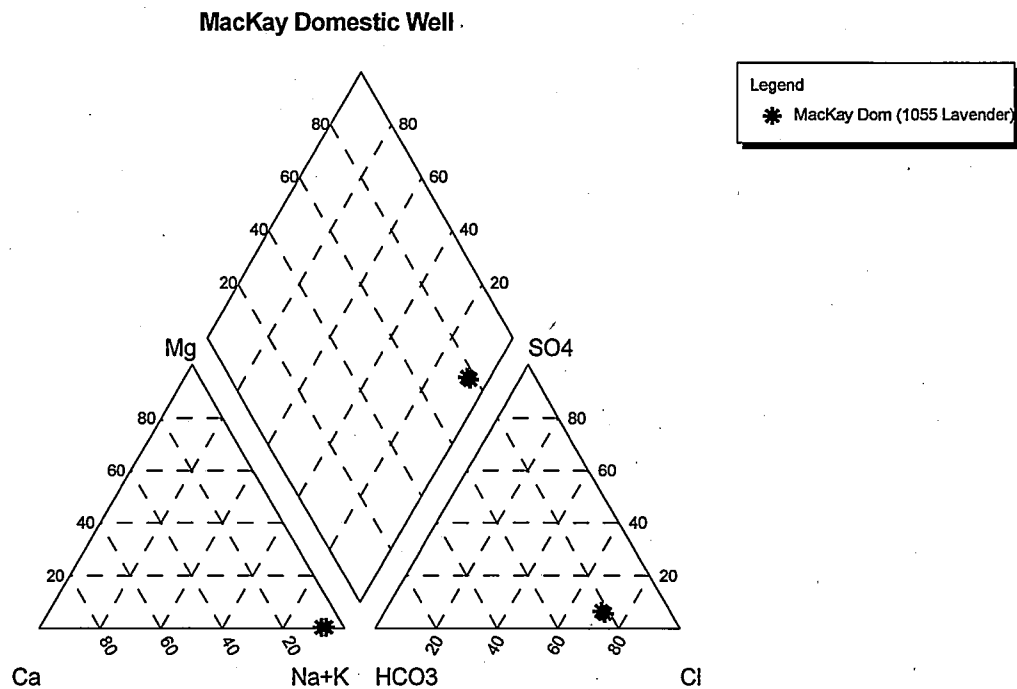
By 1993, various responses were seen in these three wells; Johnson/Woods had an increase in HCO<sub>3</sub>, Peigh domestic remained unchanged and Herz domestic had a significant increase in Na-Cl ions. The late 1990's, showed no further change in hydrochemistry for Johnson/Woods and Peigh domestic wells. During this time, however, Herz domestic appears to have recovered from geothermal water, to predominately Ca-HCO<sub>3</sub> alkaline water.

Overall, the processes controlling the hydrochemistry of these wells appear to be related through surface recharge and unrelated through geothermal activity.



### MacKay Domestic

Water analysis for the MacKay domestic well were conducted from 1987 until 1990, data shows the major ionic species to be sodium and chloride.

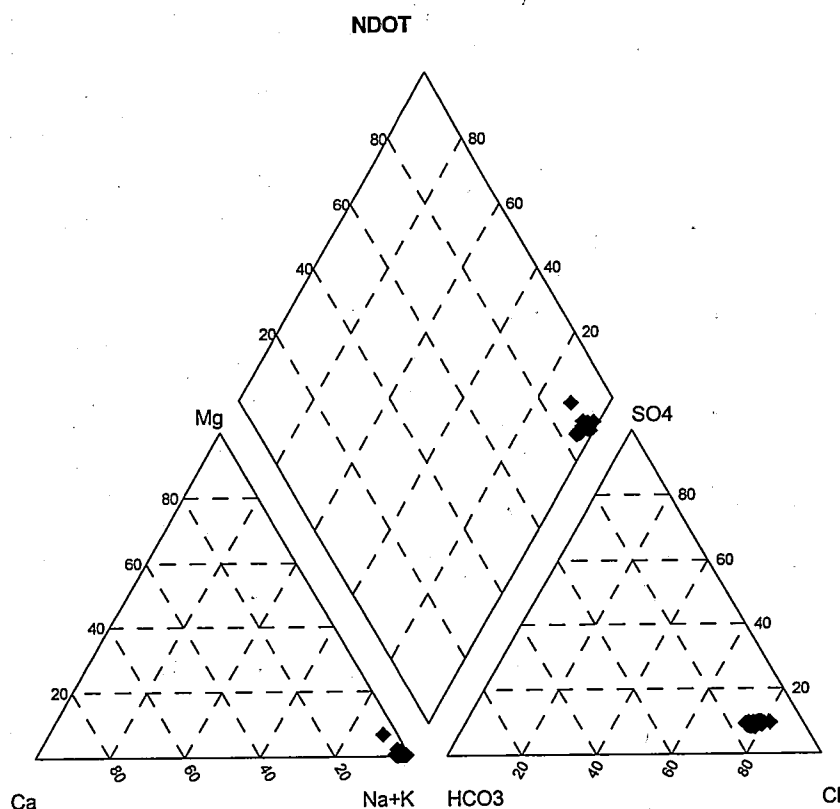


Interesting to note: MacKay domestic also had elevated values for SO<sub>4</sub> (approximately 100 meq/L), typical of other geothermal waters in area (like Curti Barn), and elevated values of Flouride (approximately 2.4 meq/L), similar to PW-1, PW-2, NDOT values, but not Curti Barn. Curti Barn had lower values of F depicted throughout the collection of water analysis. Also, MacKay domestic has a record of field pH 6.



## NDOT

According to the piper diagram, sodium and chloride have been the dominant ionic species in Nevada Department of Transportation's well since water analysis began in 1995.

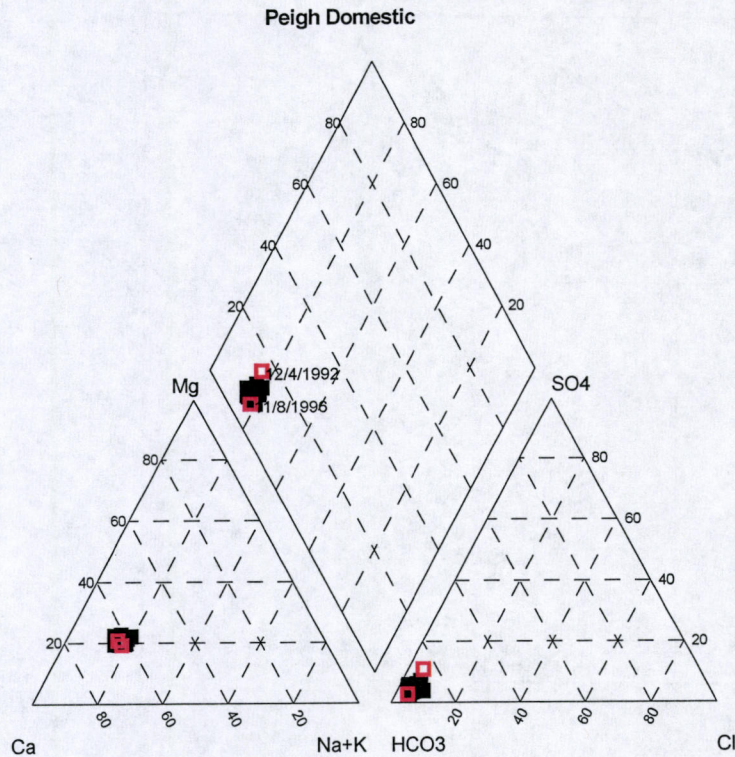


The one data point slightly outside the main cluster of points seen above depicts slightly elevated percentages of Ca and Mg in March 2006. Otherwise, data shows no change from geothermal properties. The importance of this monitoring well must be its location and establishing a known geothermal zone outside of the Steamboat Hills geothermal production area.



### Peigh Domestic

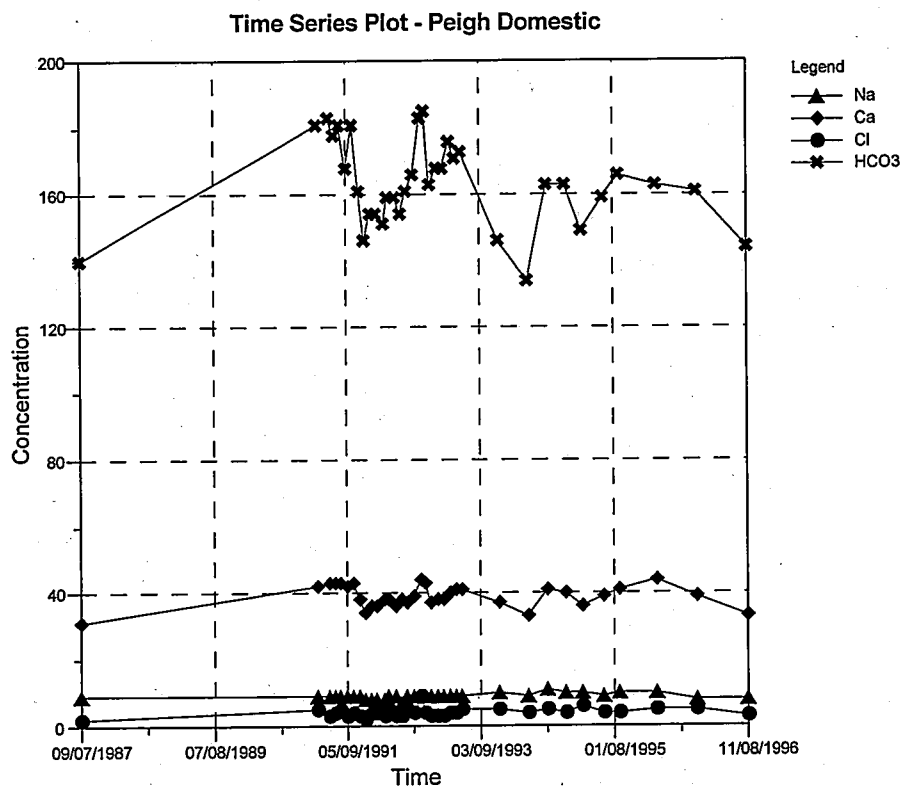
According to the piper diagram, the Peigh domestic water analysis depicts calcium bicarbonate type water with a conclusive bicarbonate/carbonate facies on the quadrilateral.



The well appears to have had no reflection in ionic speciation from wet/dry period variations or geothermal energy production. The water chemistry changed very little over the approximate ten years of data collection.



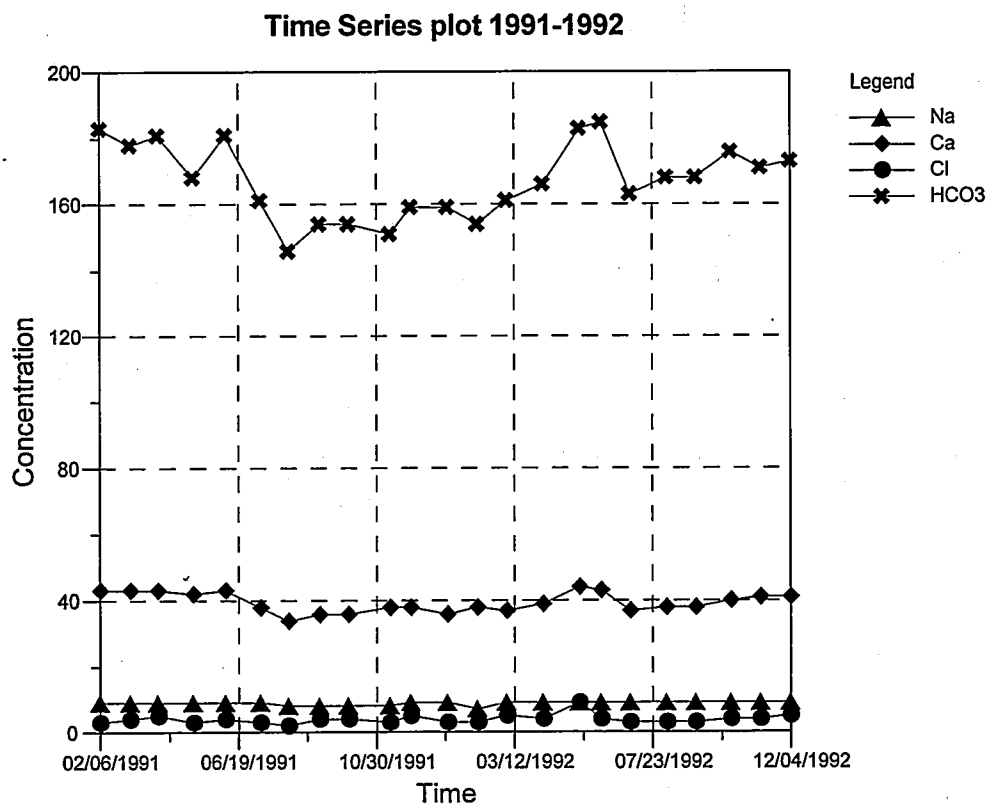
The following time series plot shows the minimal change in hydrochemical facies from another perspective.



The water type for Peigh domestic is actually Ca-Mg-HCO<sub>3</sub>, however Mg has not been plotted on the time series so the viewer may clearly see the consistent low levels of sodium and chloride.



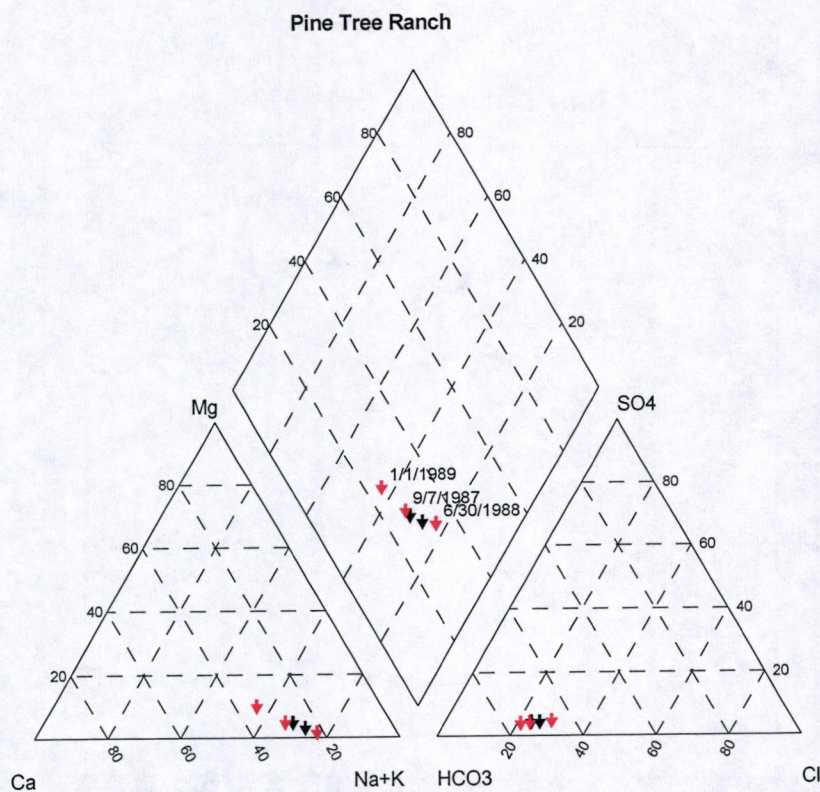
Expanding Peigh domestic's 1991 – 1992 sample data, a correlation with minor ion fluctuation and annual precipitation can be seen month to month.





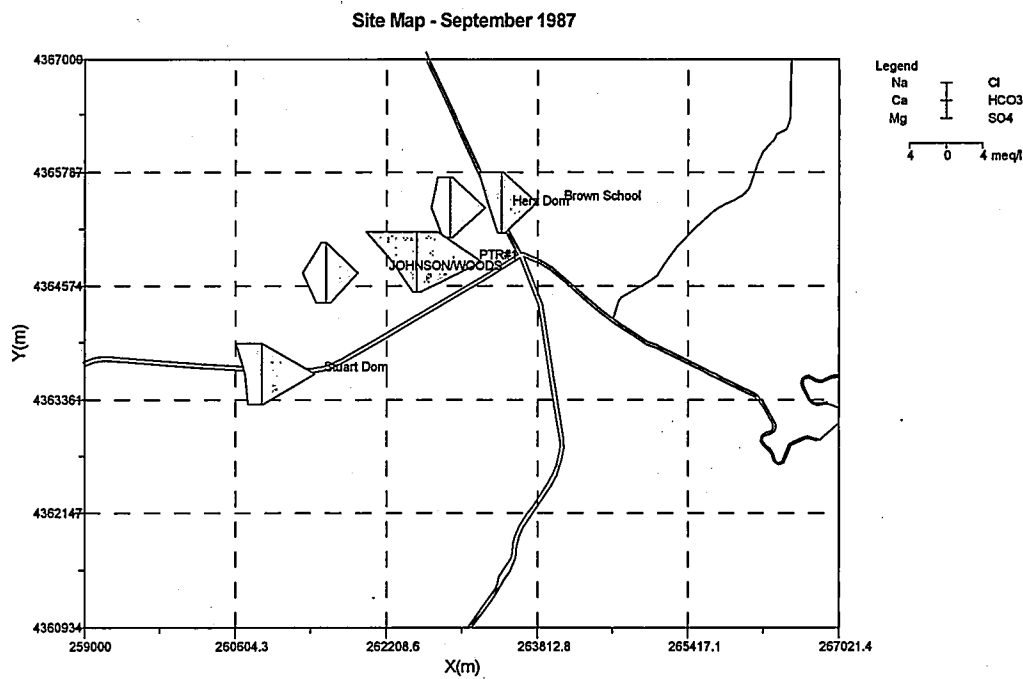
**PTR #1**

Two years of data collection for the Pine Tree Ranch well show sodium or potassium and bicarbonate ionic speciation.



Data collected early September 1987, was available for surrounding area wells. Plotted together, one can make observations of the spatially associated hydrochemical facies.





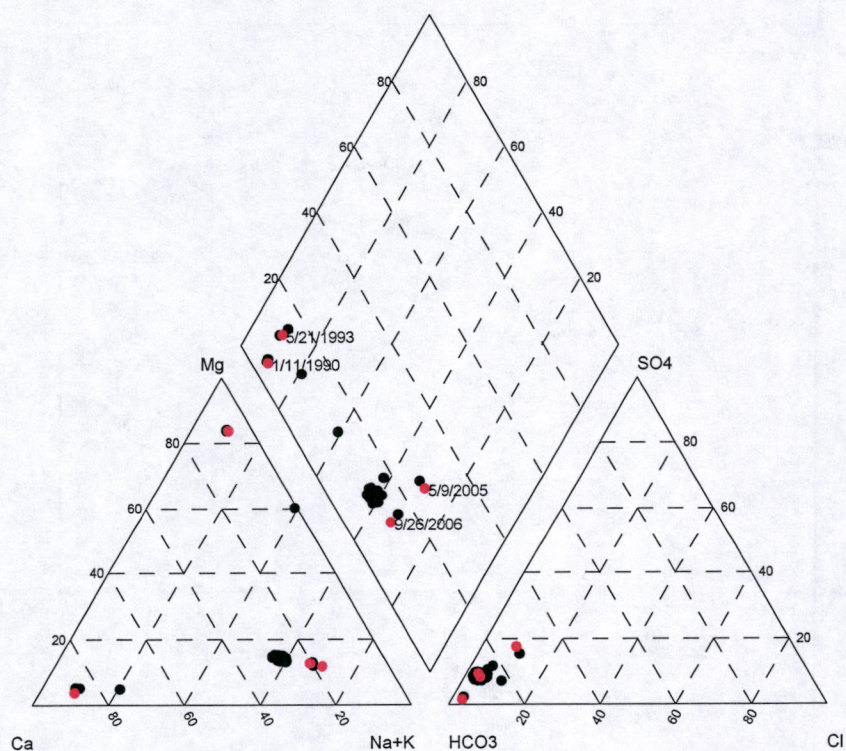
A snapshot of domestic wells located NE of the geothermal production zone shows HCO<sub>3</sub> as the predominant anion and a fairly even dispersion of cations. Ion exchange between water and solid surface may account for variations in Na, Ca and Mg in solution. PTR#1 is the only well showing Na-Cl. On the above scale, it is present in low amounts and may be indicative of some mixing of water types. Should collection of sample data for PTR#1 been expanded (in the years before and after existing records), it would have been interesting to see if a trend toward infiltrating geothermal waters existed.

### Rogers

Data collection for Roger's well in Pleasant Valley has been analyzed for approximately 20 years. The water type is predominately Na-Ca-HCO<sub>3</sub>. Throughout the time span there is a scatter of 14/126 samples that have plotted in each corner of the cation ternary diagram. It is unusual for one well to have Mg-HCO<sub>3</sub>, Na-HCO<sub>3</sub> and Ca-HCO<sub>3</sub> as different dominant water types. Looking at sample dates and water types, it would be convenient to pick out a trend to this anomaly. The following piper plot highlights a few sample dates of the scattered points.

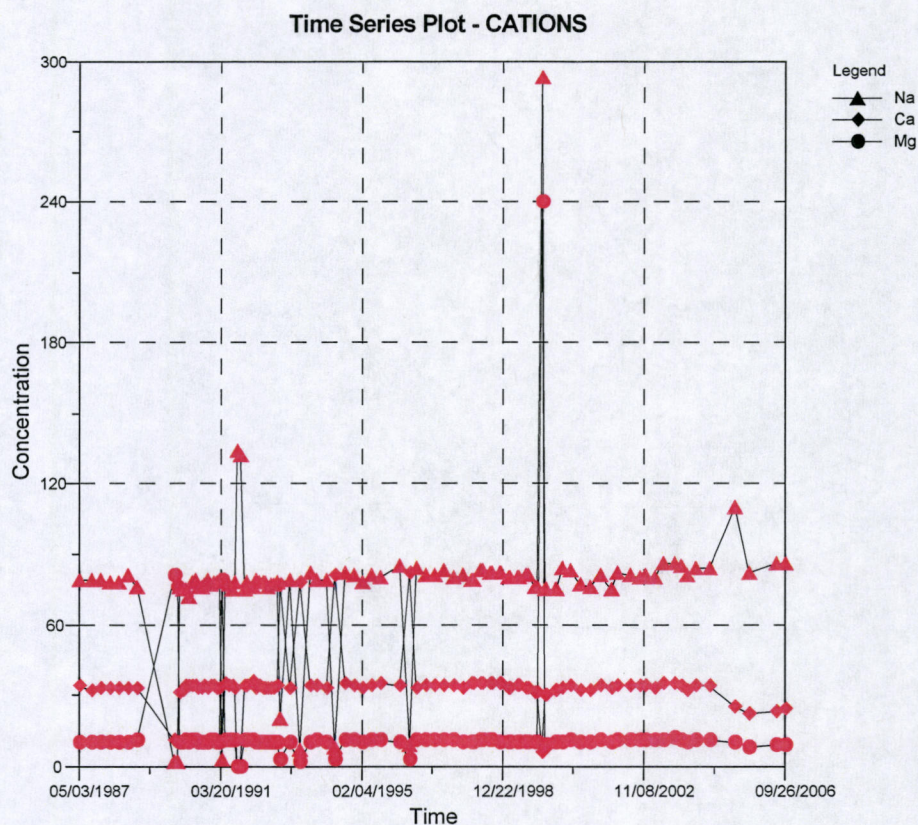


Highlighted dates of Extreme Cation Concentration



The early 1990's showed variation between Mg (1989-1991) and Ca (1992-1996) as the dominant anomalous cation, with the exception (not shown) of Na-HCO<sub>3</sub> water collected in the fall of 1991. From 2000 to 2006, Na-HCO<sub>3</sub> was the water type occurring a handful of sampling times. Considering drought years, one has to ask, would cations and not anions (namely HCO<sub>3</sub>) be affected by dry vs. wet periods? These blips in an otherwise hydro-chemically stable well may be unexplainable.



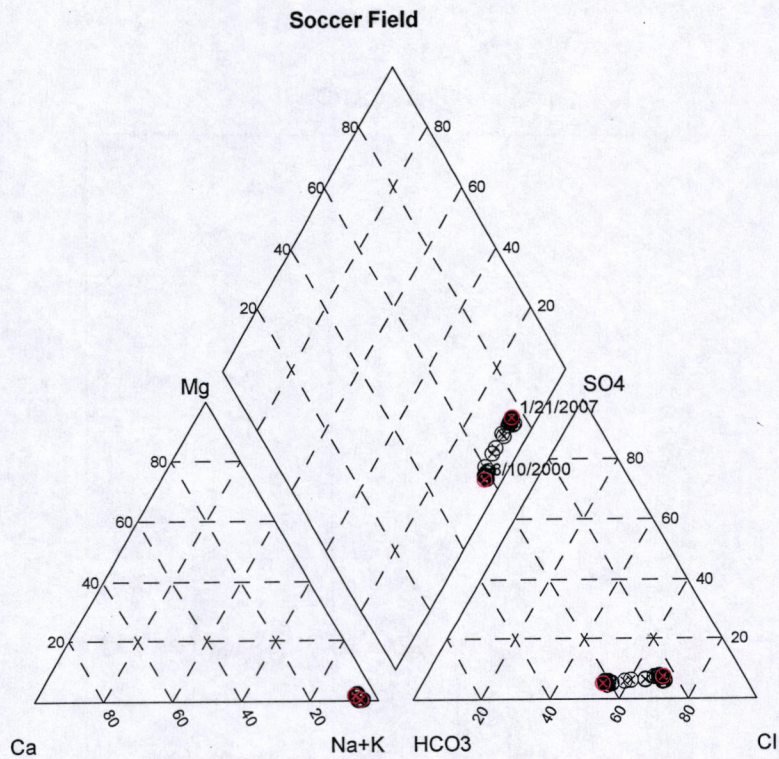


The time series plot further emphasizes the Na-Ca-HCO<sub>3</sub> water analyzed in Roger's well, with what appears random variation in the data. Note Cl ion averages 6-7 mg/L throughout collection period.

### Soccer field

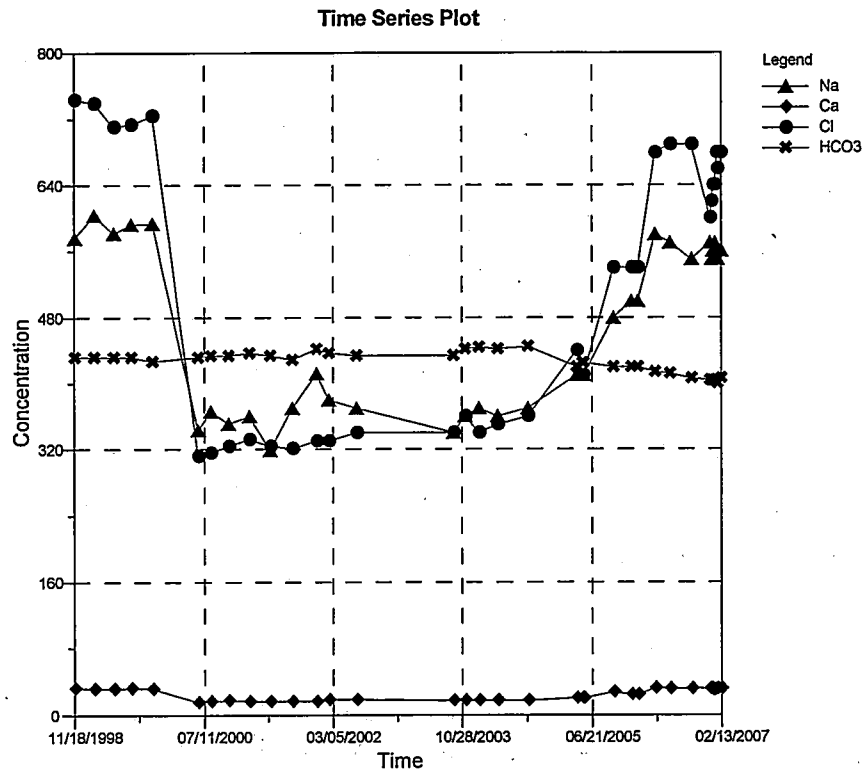
The piper diagram for the Soccer field well shows sodium as the major cation and chloride as the increasingly major anion. The data is clumped and has no definitive correlation with geothermal production activities or annual precipitation. The water remains in the sodium/potassium hydrochemical zone with an alkalinity between 20-40 percent over the 10-year sample collection time scale.





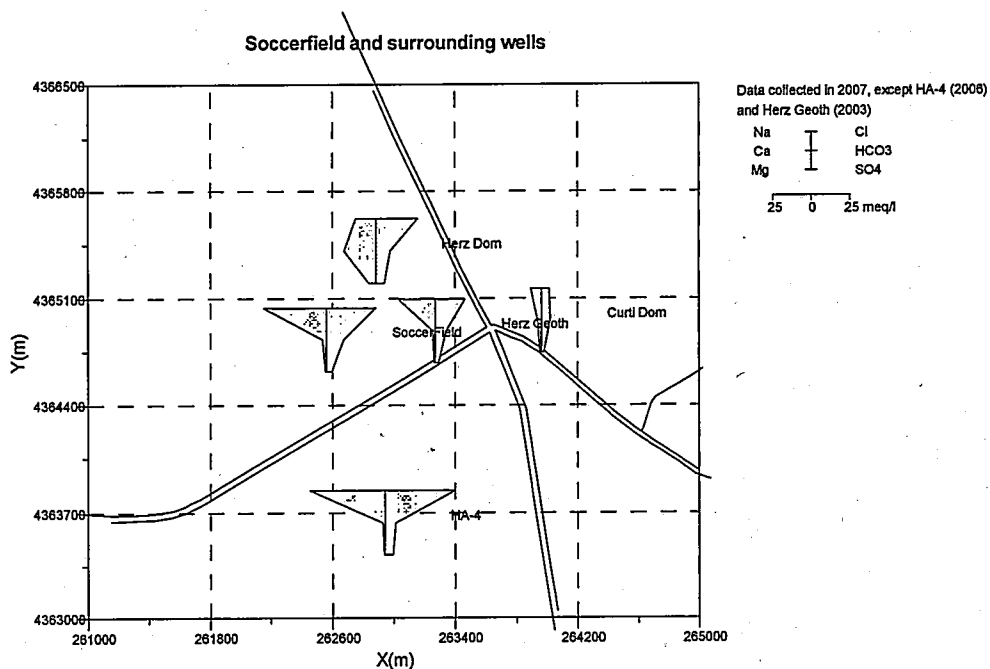
Correlation between the Caithness injection well, 64A-32, coming on-line in 2005 and the increase in chloride ions is not conclusive, although notable. By looking at the time series plot, one can view a clearer path Na-Cl has taken over the last 10 years.





The above plot shows HCO<sub>3</sub> ion levels have remained constant; therefore the well appears to be uncorrelated with annual precipitation changes through dry and wet periods. It also depicts a swing in Na-Cl ions, possibly caused by geothermal activities in a steady state aquifer. The question remains if the geothermal activity, seen as Na-Cl fluctuation, is from natural state discharge or injection of spent geothermal fluids, since there is an increase in Na-Cl ions beginning in 2005.

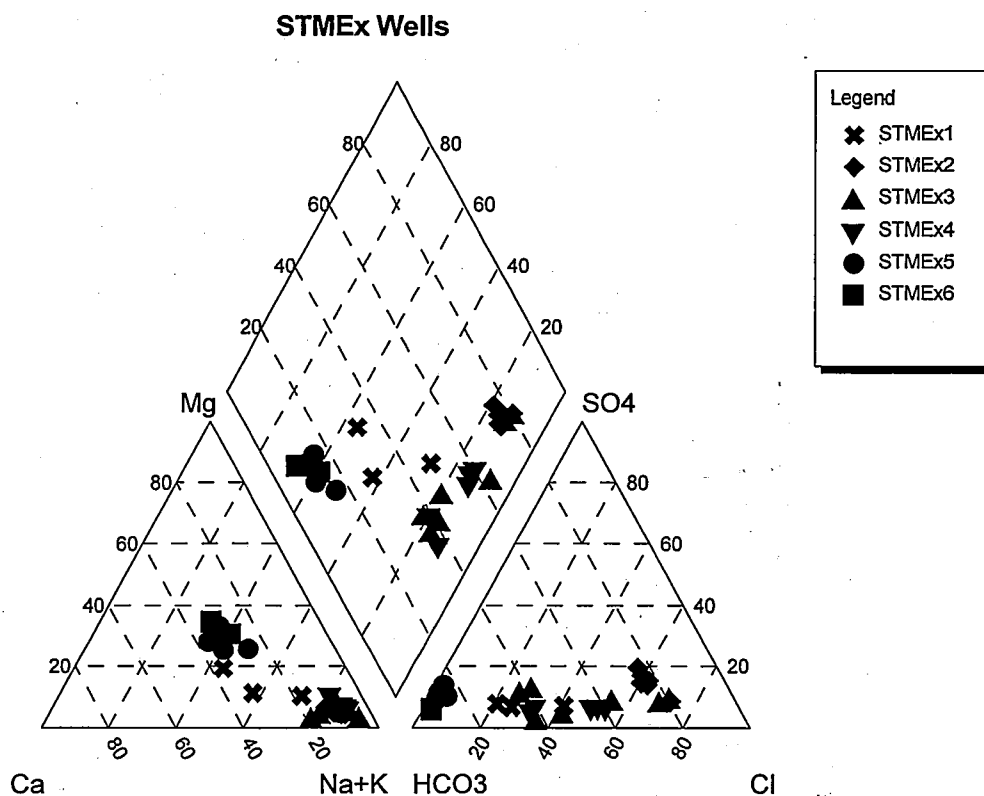




Recent data immediately west of Soccer field is unavailable, but would be interesting in the above map. It does not seem plausible that activity (i.e. draw-down) in the surrounding area, would be affecting the Na-Cl ion swing observed in Soccer field well data, since a similar stiff diagram outline is not observed in Herz domestic or Curti domestic water analysis also collected February 2007.



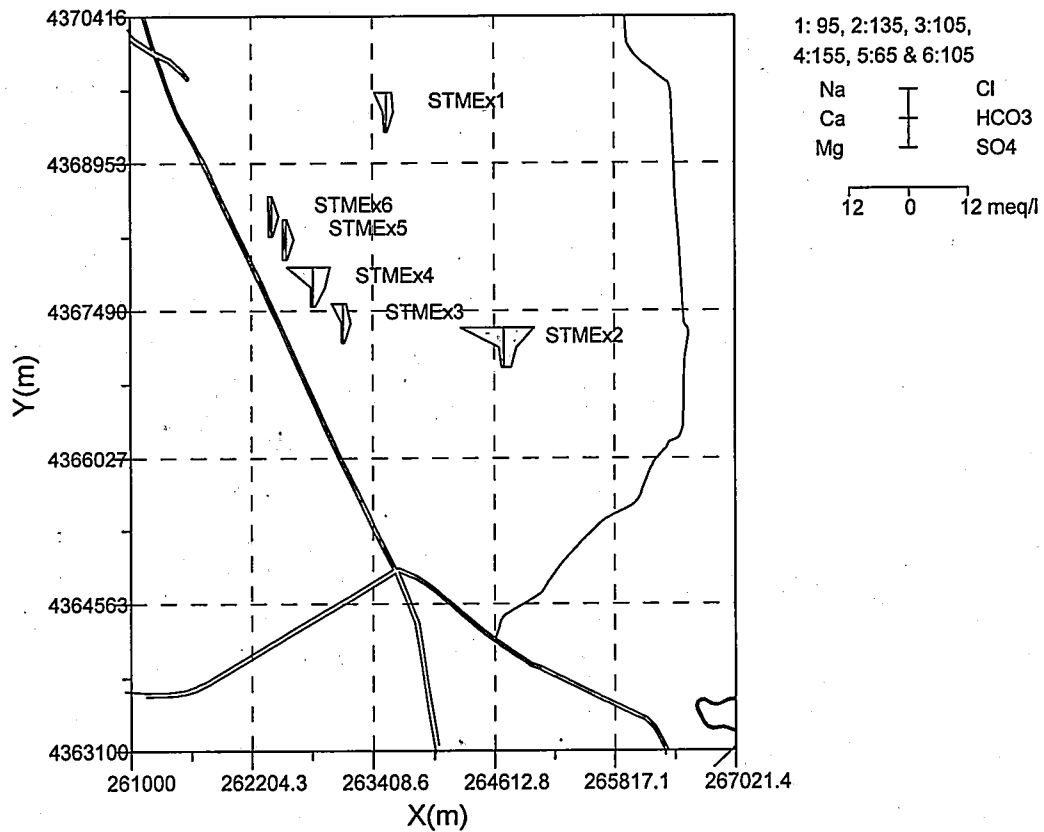
## STMEEx Wells 1-6



The county's STMEEx wells 1-6 are located on the valley floor in south Truckee Meadows. Sample data was collected for specific sections on one day, in order to record the change in hydrochemical facies with depth. As the above piper diagram shows, each well has its own unique chemistry, with a couple of trends discussed below. Overall, STMEEx 5 & 6 plot favorably for drinking water; 2,3 & 4 show a geothermal type water or mixing of waters and well 1 plots in between, (possibly not deep enough, at 300 ft, for a thorough assessment).



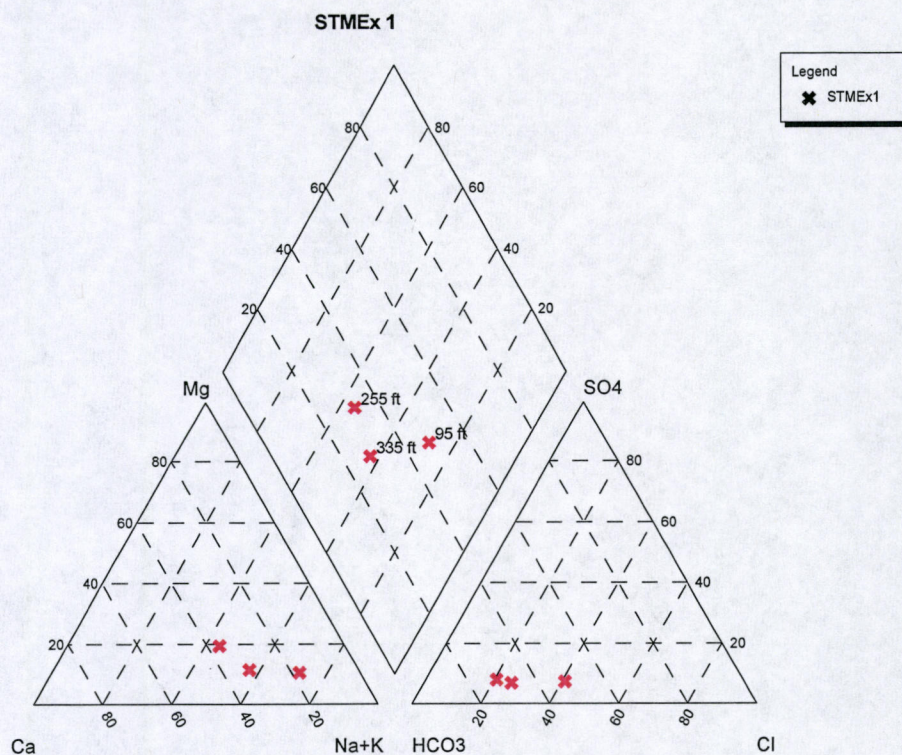
### STMEx Shallow Depth



The shallowest sample depth has been plotted with a stiff diagram depicting data for comparison. STMEx 1, 2 and 4 have the most ions present within the initial 150 ft below the surface, sample depth has been recorded in feet as reported in the legend of the map.



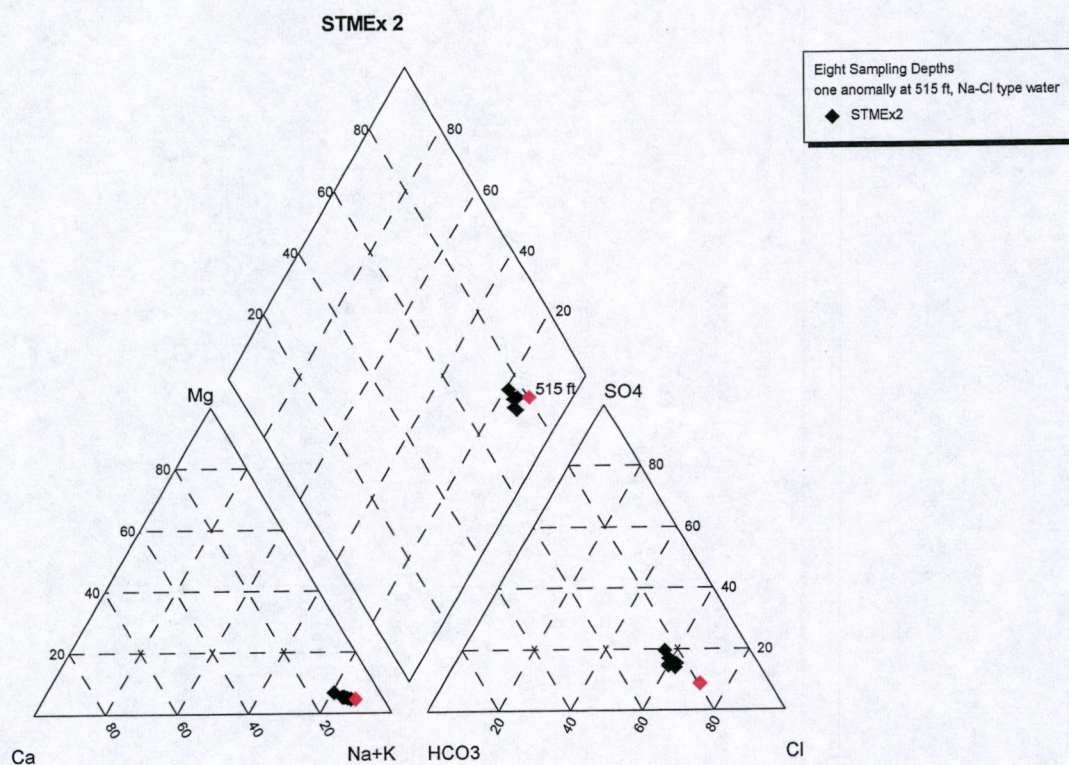
In STMEx 1 the highest total dissolved solids (TDS) occurs within the 90 –100 ft zone, with elevated levels of sodium, chloride, sulfate and boron.



This could be a result of evapotranspiration on the valley floor. Evaporates from geothermal discharge processes and salts from Steamboat Creek most likely have contributed to the elevated levels of total dissolved solids in the near subsurface.



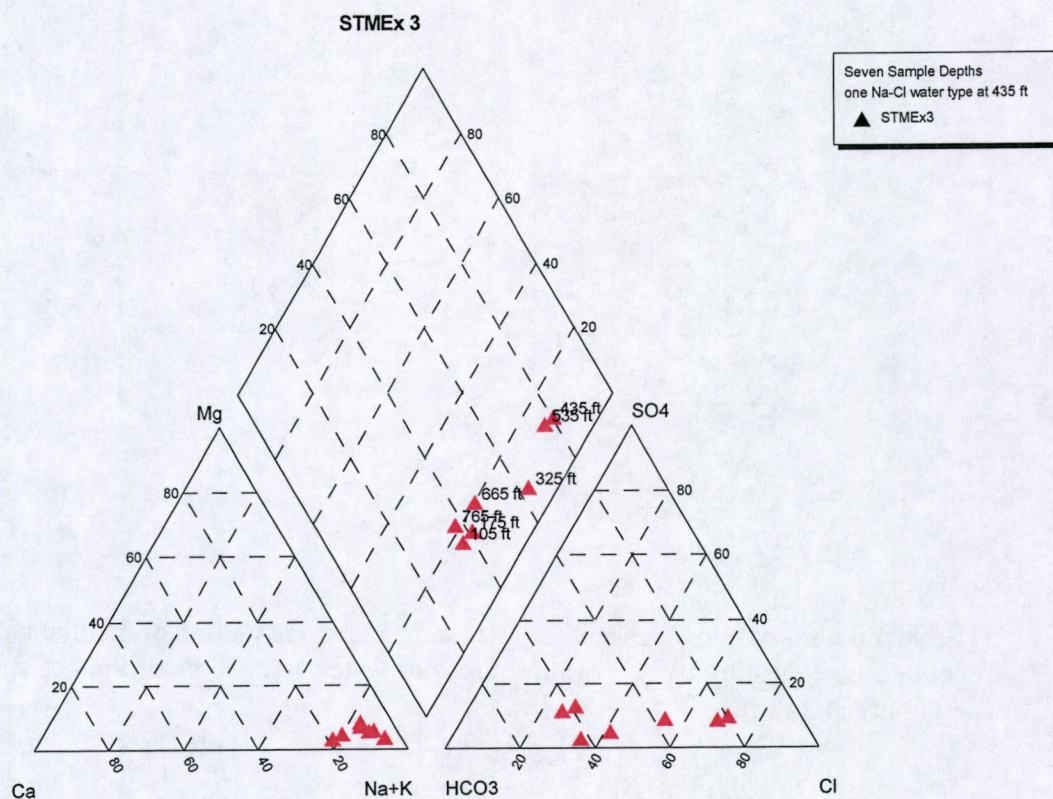
STMEx 2 has a value of 1200-1300 mg/L TDS throughout the eight sampled zones. TDS spikes up to 1700 mg/L at the 510-520 ft zone showing an increase in Ca, Mg, Na, HCO<sub>3</sub>, Cl, and B, with K and SO<sub>4</sub> decreasing.



The maximum temperature, as reported by GeothermEx, Inc. (2007), is 127 degrees Fahrenheit, implying STMEx 2 has tapped into a geothermal source.

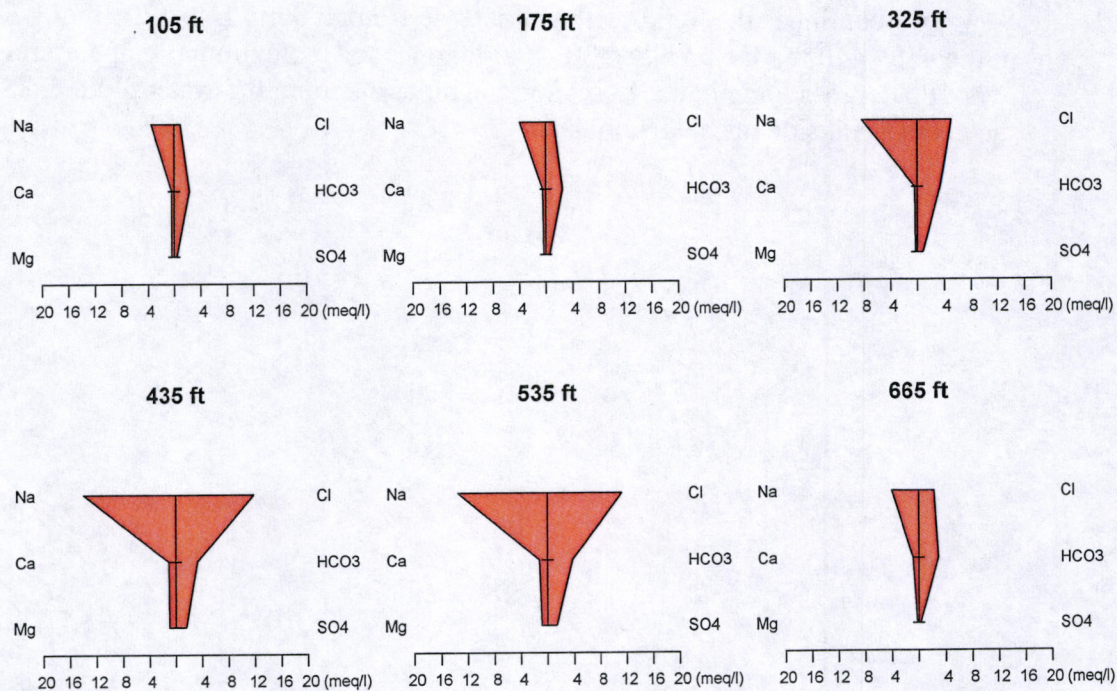


STME<sub>x</sub> 3 continues the trend, with an increase from 400 mg/L to 1200 mg/L TDS in the 430 –440 ft zone and the 530 –540 ft zone, and a maximum temperature over 100 degrees Farenheit. As seen in the piper diagram, the water plotted on the geothermal side of the diamond.





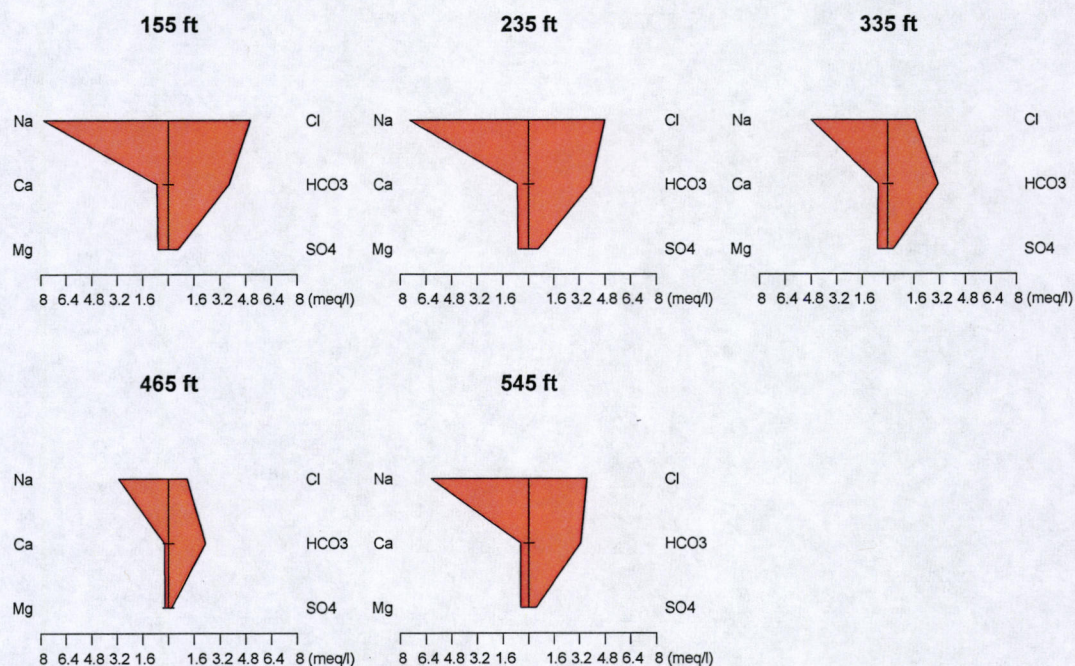
The percentage of Na and Cl ions is significantly lower < 435 ft and > 535 ft, as seen below.



The stiff diagrams show descending perforated sections with their resultant chemistry, suggesting two separate sources of water, with some mixing of waters beginning at 325 ft.



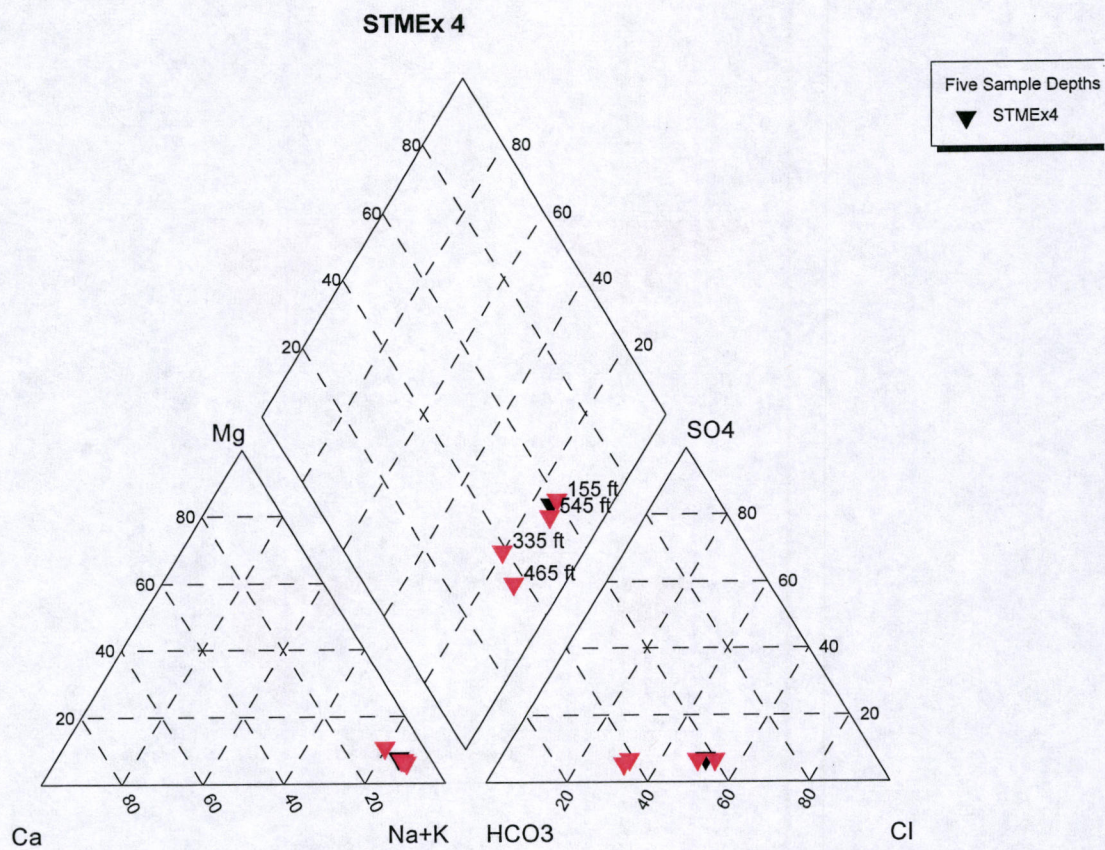
STME<sub>x</sub> 4 varies without any clear trends, a few sampled depths show increased Na, K, HCO<sub>3</sub>, Cl, SO<sub>4</sub>, B and TDS, but are not as definitive as STME<sub>x</sub> 2 and 3 for depicting separate sources. Mixing of fresh and geothermal water is suggested by the relative abundance of Na, Cl and HCO<sub>3</sub>, as observed in the stiff diagram layout below. (Please note the meq/L scale change from previous well data.)



The first two samples show elevated Na-Cl-HCO<sub>3</sub> ion constituents, with 660-720 mg/L TDS; at 465 ft depth, the Na-HCO<sub>3</sub>-Cl water is 320 mg/L TDS; and at the bottom perforation, Na-Cl-HCO<sub>3</sub> water analysis showed 550 mg/L TDS.

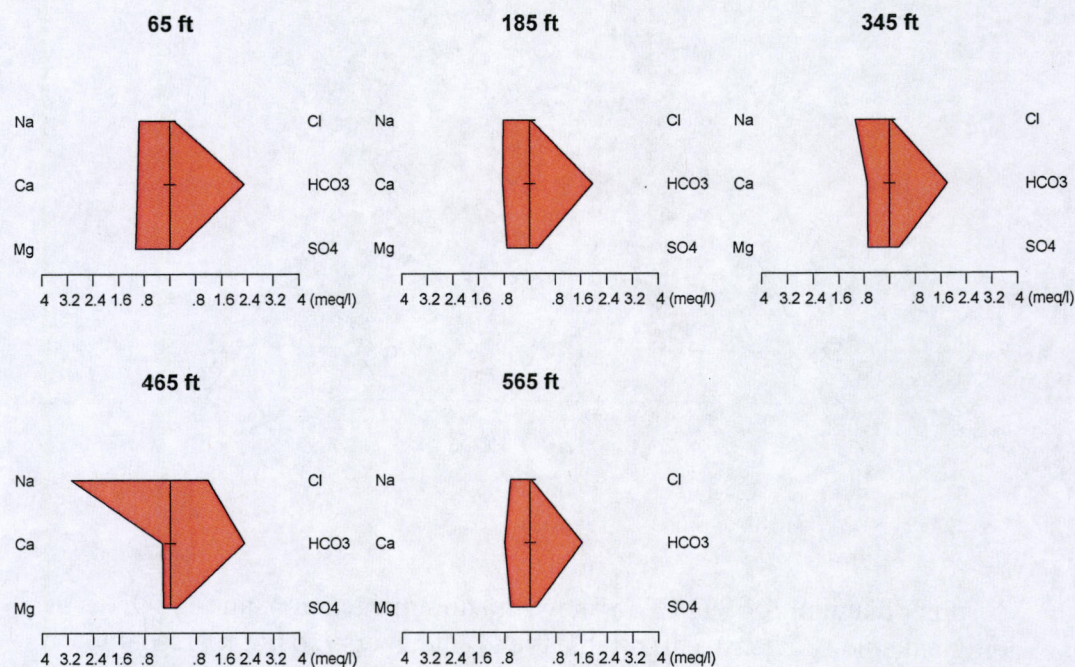


The piper plot for STMEx 4 shows low alkalinity (acidic) water type, high in Na and K with no dominate anion between HCO<sub>3</sub> and Cl.



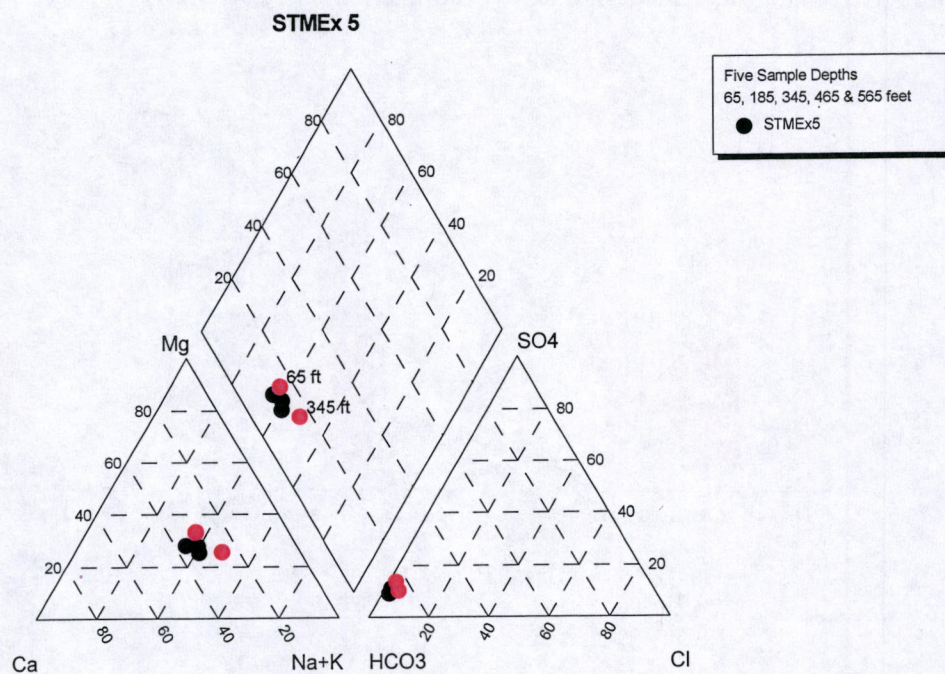


STMEx 5 may appear to follow the trend, of increased TDS between 400-500 ft depth, in the following stiff diagrams. However, this may not be so, since Cl and B do not increase and the TDS remains low (approximately 200 mg/L).



The descending perforated sections show an overall low ion constituency, with a change in cations (plus Cl) at 465 ft. On the scale shown above, the change represented in the stiff diagrams is small.

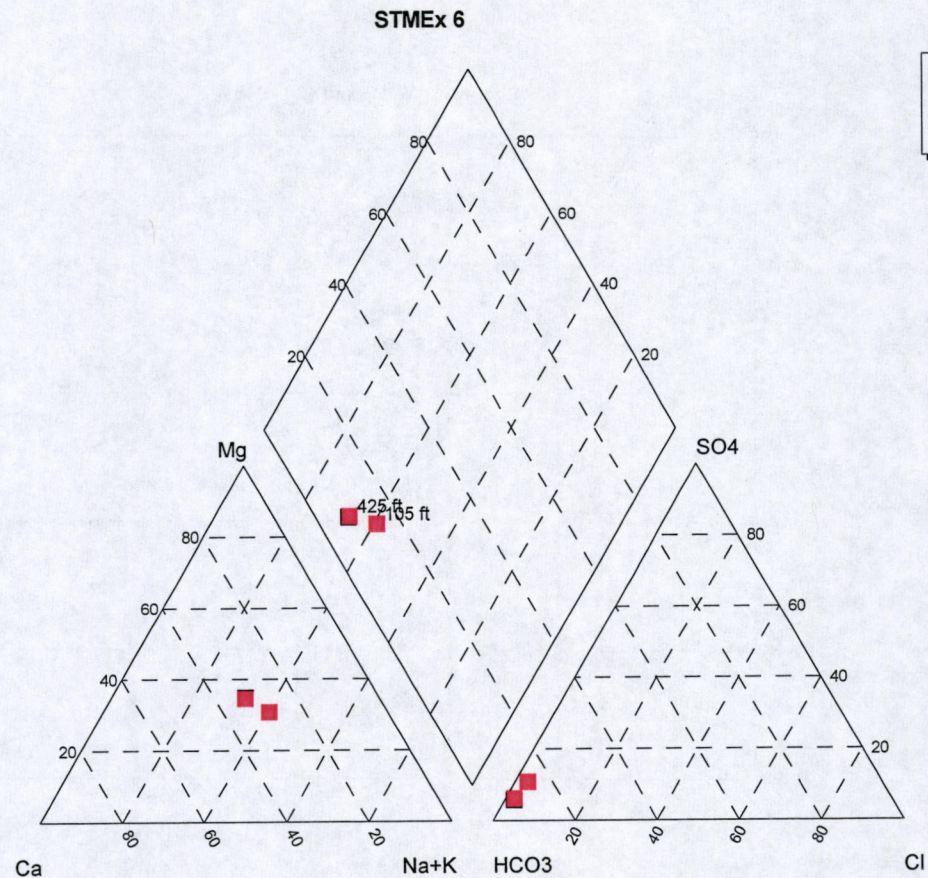




The piper diagram for STMEx 5 shows no dominant cation, and HCO<sub>3</sub> as the dominant anion. The two highlighted 'end-members' do not represent the anomaly seen in the stiff diagrams. Therefore it is inconclusive that mixing of water types is occurring at this location.

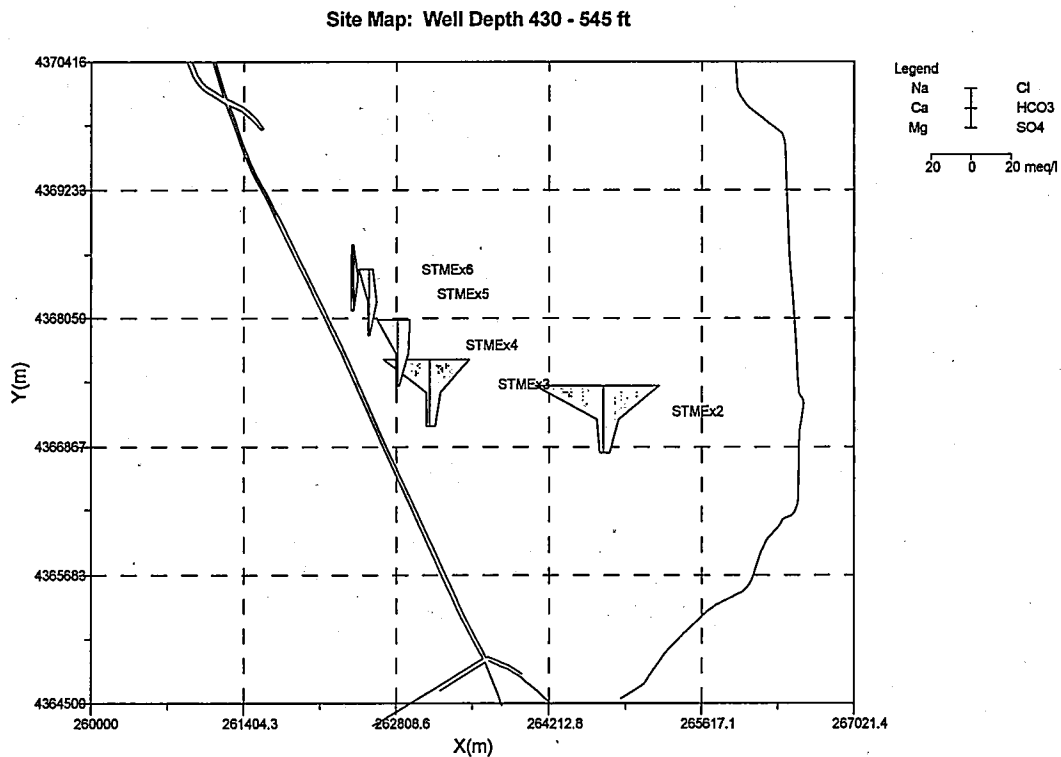


STMEx 6, located the furthest west, has a piper diagram showing drinkable quality water type, with < 250 mg/L TDS.





A final map of stiff diagrams using data sampled at 400-500 ft is worth showing for spatial association of the chemical activity.



The map suggests mixing of geothermal water (present in STMEx 2 and 3) decreases to the NW since the ion representation plotted in the Stiff diagrams drop off in that direction; note the low levels of ions (especially Na-Cl) shown in STMEx 5 and 6.



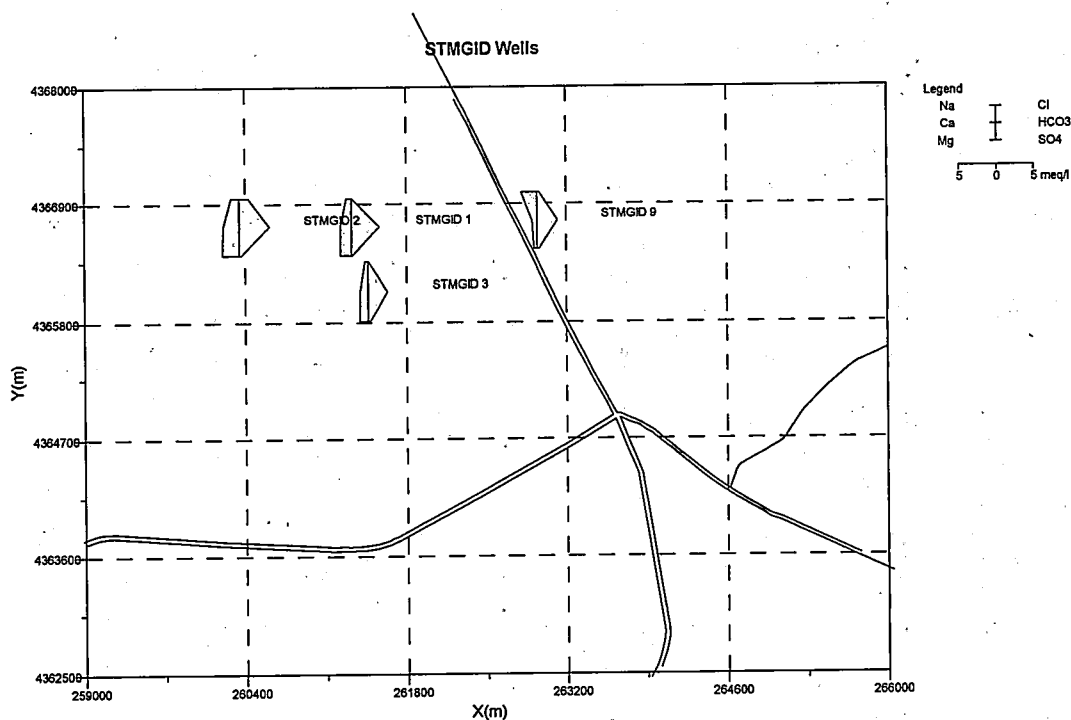
Table of Sample Data with highlighted values:

<i>Name</i>	<i>Sample Depth</i>	<i>Ca</i>	<i>Mg</i>	<i>Na</i>	<i>K</i>	<i>HCO3</i>	<i>Cl</i>	<i>SO4</i>	<i>TDS</i>	<i>B</i>
STMEx1	330-340 ft zone	18	3.8	31	9.4	108	18	9.2	220	1
STMEx1	250-260 ft zone	24	7.6	27	10	120	26	9.2	230	0.94
STMEx1	090-100 ft zone	19	6.5	80	11	130	59	14	410	5
STMEx2	130-140 ft zone	30	8.7	300	32	240	330	110	1200	16
STMEx2	280-290 ft zone	34	9.8	290	31	230	360	120	1200	16
STMEx2	410-420 ft zone	35	9.9	290	31	230	340	120	1200	17
<b>STMEx2</b>	<b>510-520 ft zone</b>	<b>39</b>	<b>13</b>	<b>470</b>	<b>29</b>	<b>280</b>	<b>590</b>	<b>95</b>	<b>1700</b>	<b>25</b>
STMEx2	740-750 ft zone	35	9.9	280	31	220	310	120	1200	15
STMEx2	810-830 ft zone	39	12	260	33	220	330	100	1200	15
STMEx2	900-920 ft zone	34	9.2	270	29	220	300	140	1200	13
STMEx3	320-330 ft zone	8.3	4	190	15	210	180	40	830	11
STMEx3	170-180 ft zone	9.2	4.3	91	9.3	150	42	26	470	2
<b>STMEx3</b>	<b>530-540 ft zone</b>	<b>25</b>	<b>11</b>	<b>310</b>	<b>28</b>	<b>230</b>	<b>400</b>	<b>67</b>	<b>1200</b>	<b>19</b>
STMEx3	100-110 ft zone	7.6	4.5	80	7.8	140	33	20	420	1.6
STMEx3	660-670 ft zone	18	3.3	94	23	180	81	13	490	6
STMEx3	760-770 ft zone	18	1.9	73	24	170	55	6.1	420	5.2
<b>STMEx3</b>	<b>430-440 ft zone</b>	<b>21</b>	<b>12</b>	<b>320</b>	<b>35</b>	<b>200</b>	<b>420</b>	<b>77</b>	<b>1200</b>	<b>21</b>
<b>STMEx4</b>	<b>230-240 ft zone</b>	<b>14</b>	<b>8</b>	<b>170</b>	<b>13</b>	<b>240</b>	<b>170</b>	<b>30</b>	<b>660</b>	<b>9.6</b>
<b>STMEx4</b>	<b>540-550 ft zone</b>	<b>10</b>	<b>5.9</b>	<b>140</b>	<b>9.6</b>	<b>200</b>	<b>130</b>	<b>23</b>	<b>550</b>	<b>7.3</b>
STMEx4	330-340 ft zone	12	8	110	10	190	59	16	510	5.1
<b>STMEx4</b>	<b>150-160 ft zone</b>	<b>14</b>	<b>7.7</b>	<b>180</b>	<b>13</b>	<b>230</b>	<b>180</b>	<b>29</b>	<b>720</b>	<b>9.9</b>
STMEx4	460-470 ft zone	4.8	2.7	71	6.9	140	41	9.2	320	1.9
STMEx5	060-70 ft zone	20	13	22	7.8	140	4.5	13	250	0.09
STMEx5	560-570 ft zone	16	7.4	14	6.1	100	1.4	8.1	180	0.06
<b>STMEx5</b>	<b>460-470 ft zone</b>	<b>16</b>	<b>7.3</b>	<b>18</b>	<b>7.3</b>	<b>110</b>	<b>1.5</b>	<b>8.8</b>	<b>200</b>	<b>0.07</b>
STMEx5	340-350 ft zone	14	8.3	25	7.7	110	1.5	14	230	0.1
STMEx5	180-190 ft zone	17	8.7	19	7.3	120	1.5	12	220	0.09
STMEx6	250-260 ft zone	12	7.8	11	4.9	91	1.3	4.5	160	0.09
STMEx6	420-430 ft zone	12	7.7	11	4.9	91	1.3	4.8	180	0.09
STMEx6	100-110 ft zone	17	11	23	7.7	123	2.7	12	240	0.09



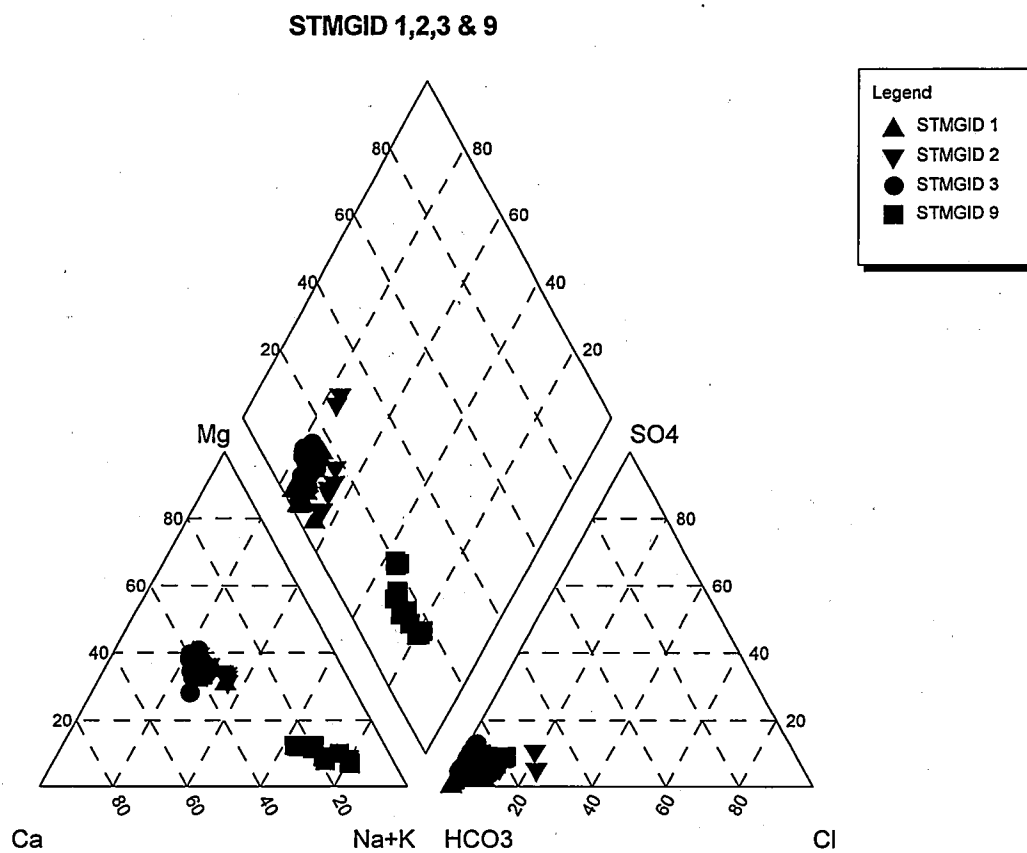
### County's municipal production wells

The South Truckee Meadows General Improvement District (STMGID) municipal production wells 1, 2, 3 and 9 are relatively close to the geothermal area and are considered responsible for a reduction of 20-30 feet in potentiometric surface between 1982 and 1992 (Widmer, 2006). STMGID 1 and 2 are located down gradient of the steamboat ditch whose irrigation water supply decreased dramatically between 1984 and 1987 (Widmer, personal communication).



STMGID 9 located on the valley floor, has a slightly different hydrochemical facies than STMGID 1, 2 and 3 wells.

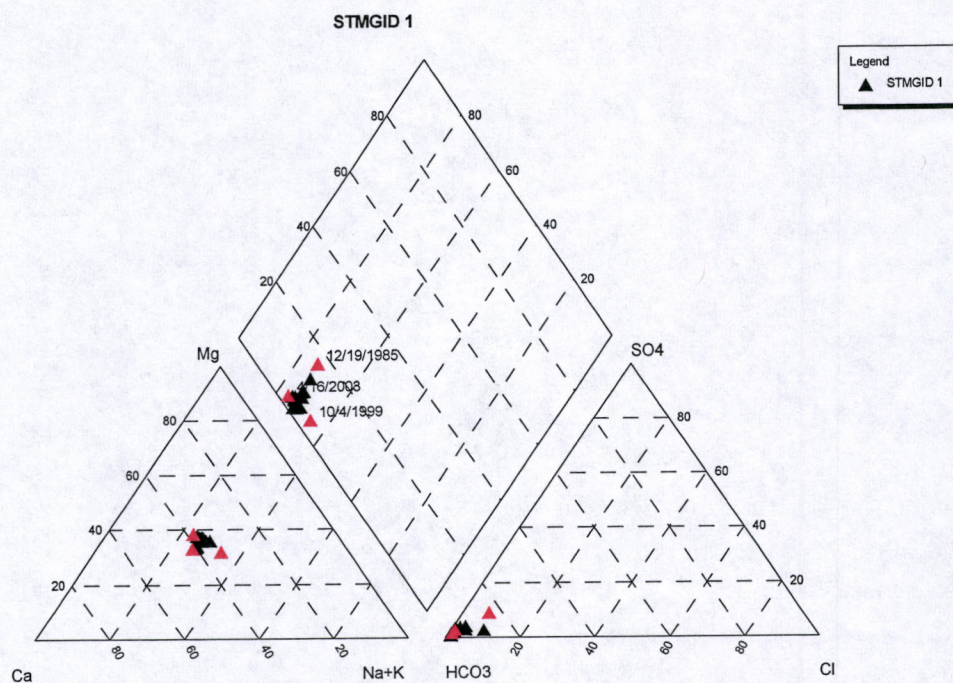




STMGID 9 production well's major cations are predominately sodium with bicarbonate anions found in solution. The variance in cations is, most likely, a function of location. Evaporates from historical flooding of Steamboat Creek and geothermal discharge processes have probably contributed to elevated salt levels on the valley floor.



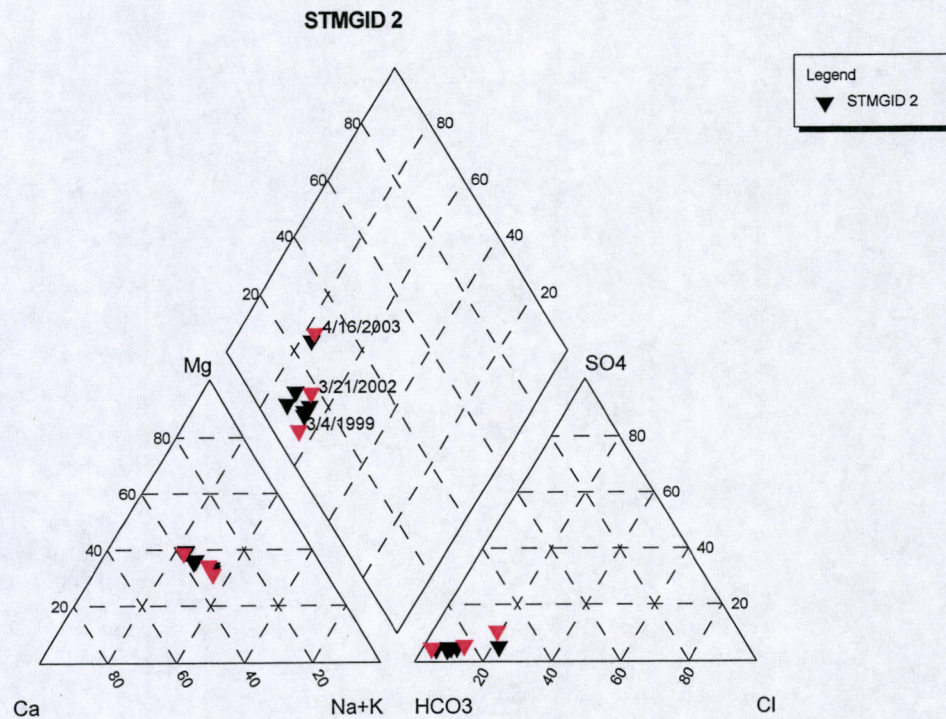
STMGID 1 water analysis data shows a slight change in ion constituents between 1985 and 1999.



Sample data from 2003 shows an equilibrium state between the two extremes plotted on the quadrilateral, which may correlate with decreased production in STMGID 1, scatter due to water collection technique or natural variations.



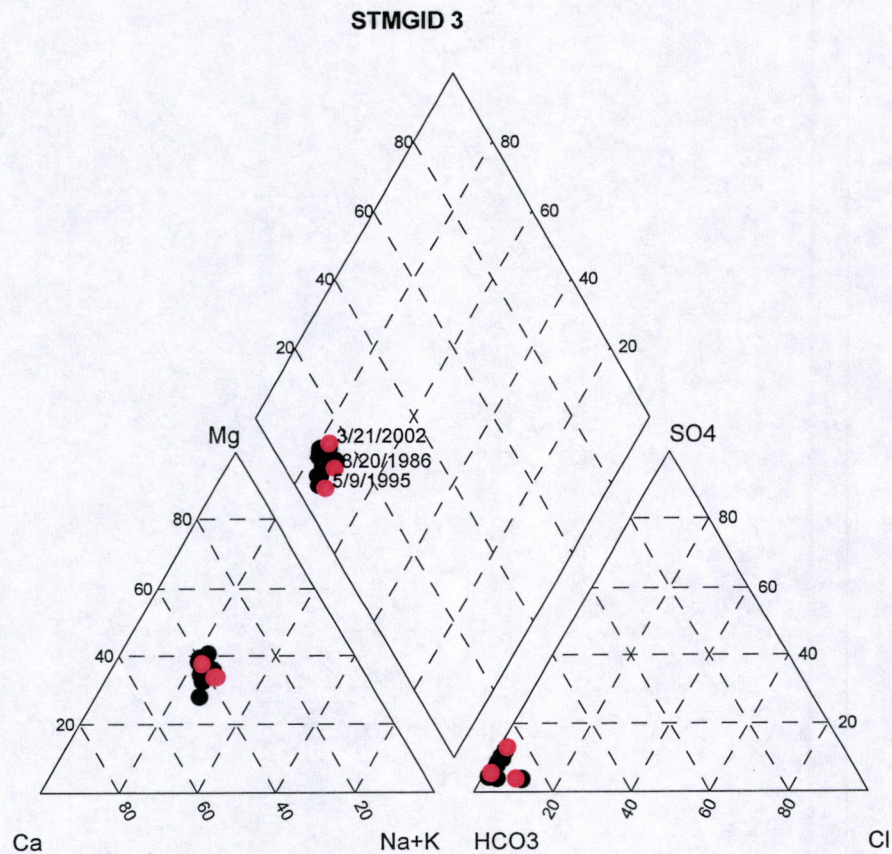
STMGID 2 production well's piper diagram shows a change occurring notably during the final five years of data collection. The most recent water analysis occurred in 2004, the point overlapped by data plotted for 4/16/2003.



The change has not affected the hydrochemical facies and is not expected to have affected water quality.



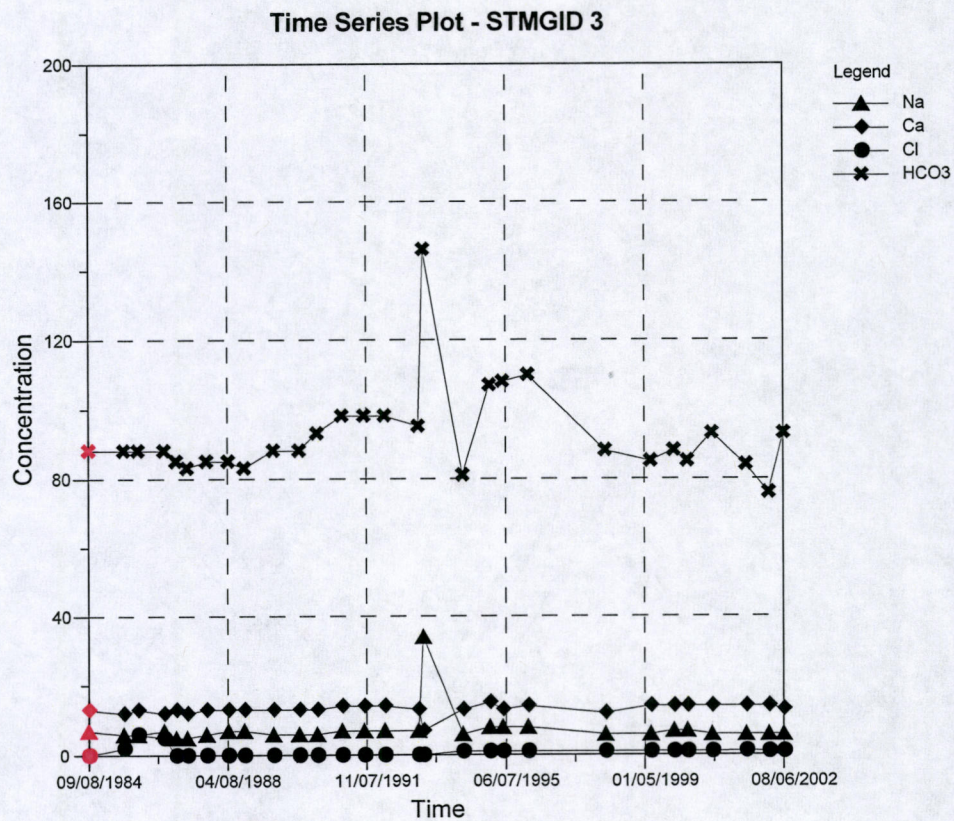
STMGID's PW-3 water analysis shows the major ions to be calcium/magnesium (60/40) and bicarbonate/carbonate.



This suggests weathering of the surrounding plutonic igneous rock, which may be more dioritic than granitic. The chemistry of the water tapped with this well has changed little over 18 years of monitoring.



The following STMGID 3 time series plot depicts the consistency of major ions in solution with a spike in Na and HCO<sub>3</sub>, during 1993.

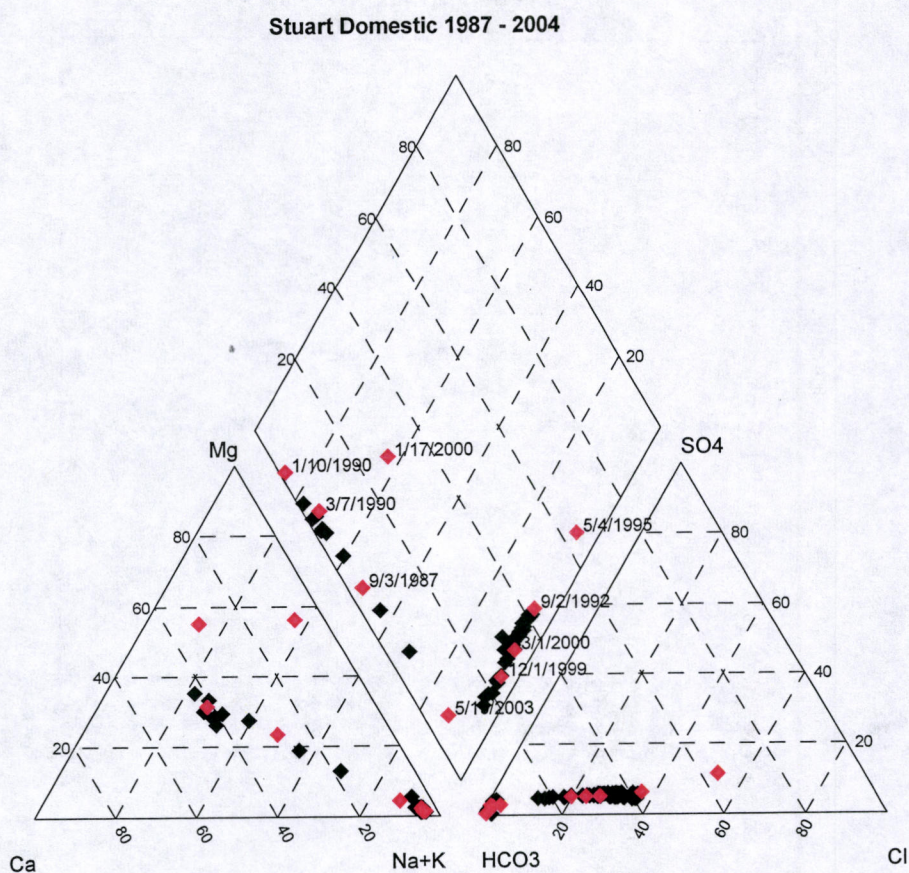


Please note the spike in Na ion is accompanied by a slight decrease in all other considered cations, which complies with the rules of stoichiometry.



## Stuart Domestic

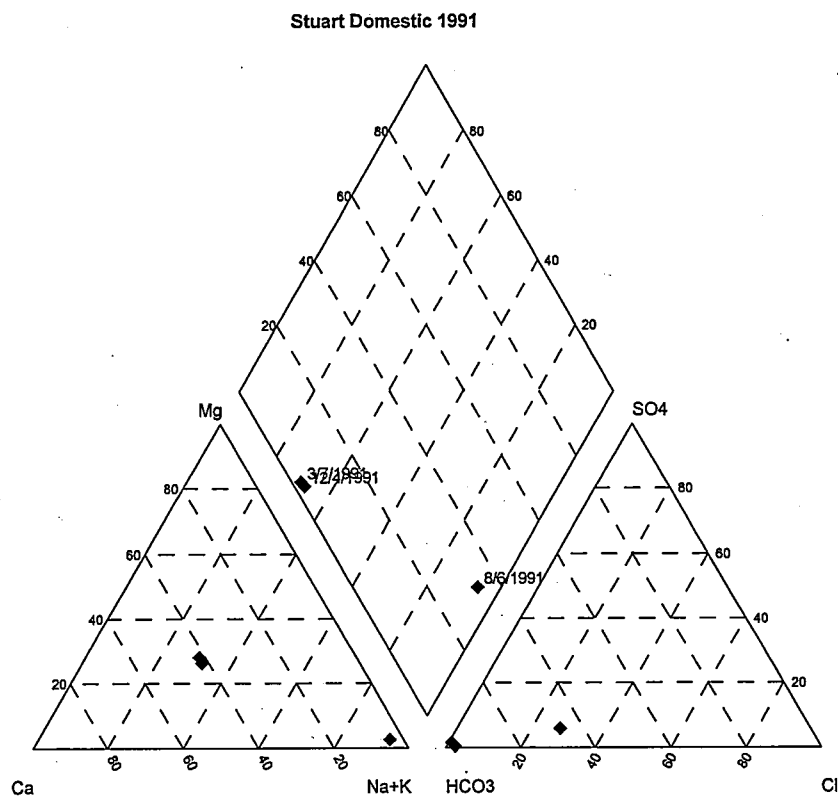
The Stuart domestic well has experienced a large change in its hydrochemical facies over the sampling period.



Chronologically, the dominant cation has become sodium accompanied by an increase in chloride. Throughout the data collection period, Ca + Mg and Na have exchanged predominance. A steady level of HCO<sub>3</sub> ions has masked the anionic change of increased levels of Cl. All of this suggests a possible mixing of fresh and geothermal waters.



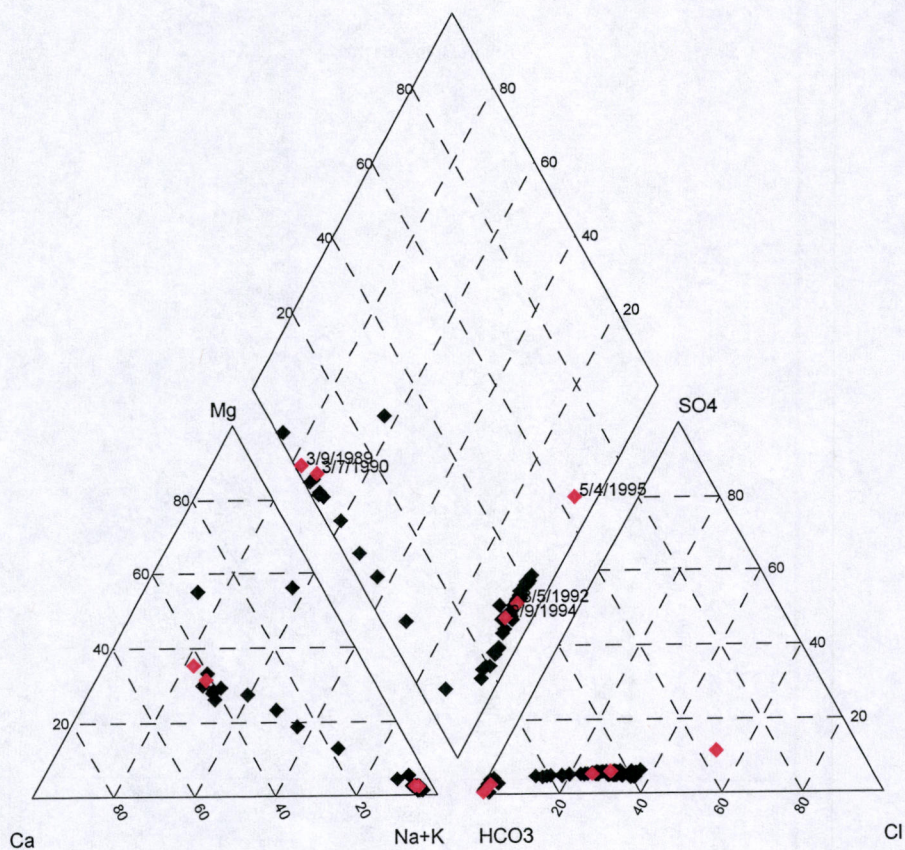
Pinpointing when the major cation changed from Ca + Mg to Na is difficult to explain. The shift occurred during 1991, with a sample collected in August plotting on the right side of the quadrilateral.



Unexplainable is why data from 12/1991, containing higher percentages of Ca + Mg, differ from 8/1991 when coupled with the fact that beginning in 1992 all data plots on the right for all months of the year. Looking at a piper diagram highlighting March of the years surrounding 1991 shows it is not a seasonal phenomenon.

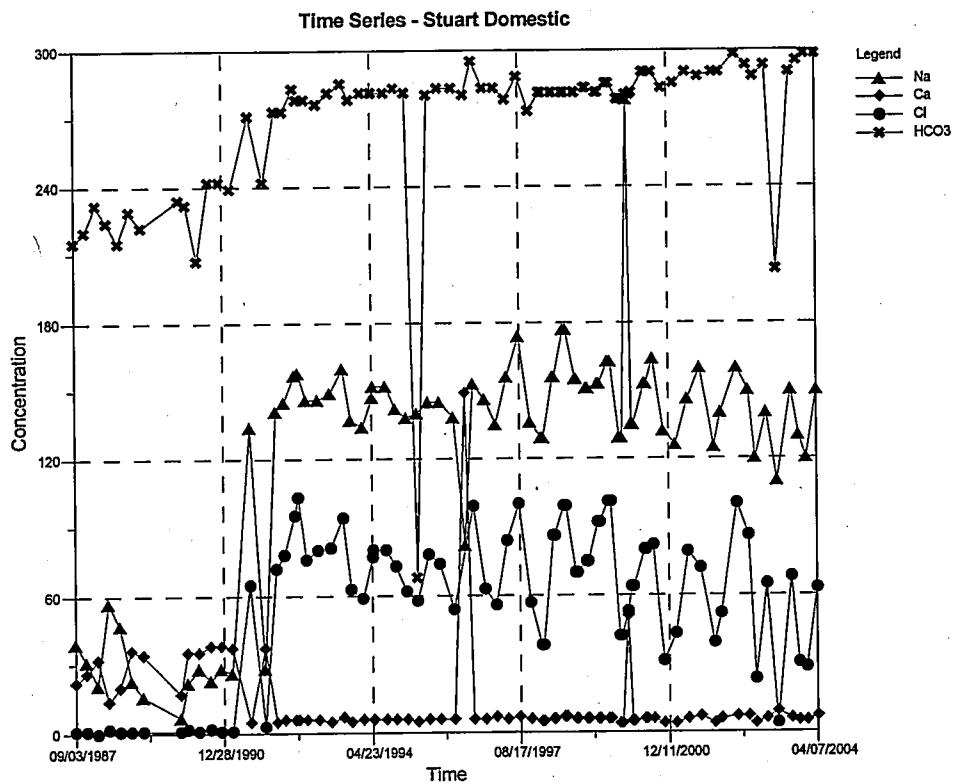


Stuart Dom - March 89 -94



Note the anomaly collected 5/4/1995, with very high percentage of Na and Cl. The trend in the cation and anion portions of the trilinear diagrams above, show the increase in Na is accompanied by an increase in Cl ion. This can also be seen on the time series plot below.

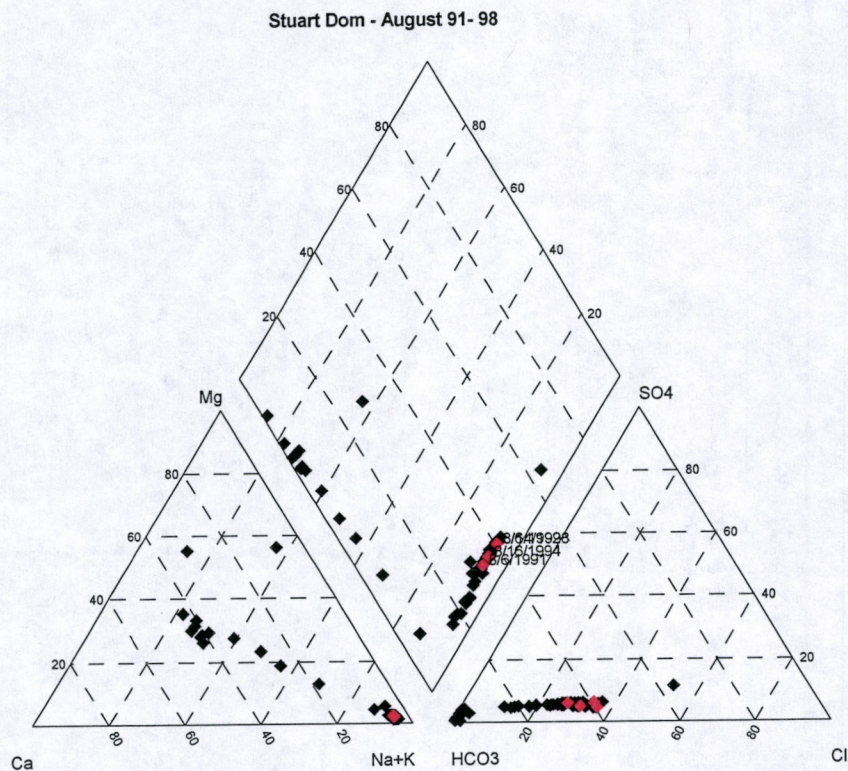




HCO<sub>3</sub> remains the major anion throughout the sample collection period. Whereas, Ca decreased to a very low percentage, at the same time Na and Cl (Cl was not present (0-2 mg/L) before 1991) significantly increased (Cl averaged 60-100 mg/L) and remained elevated throughout collection period.



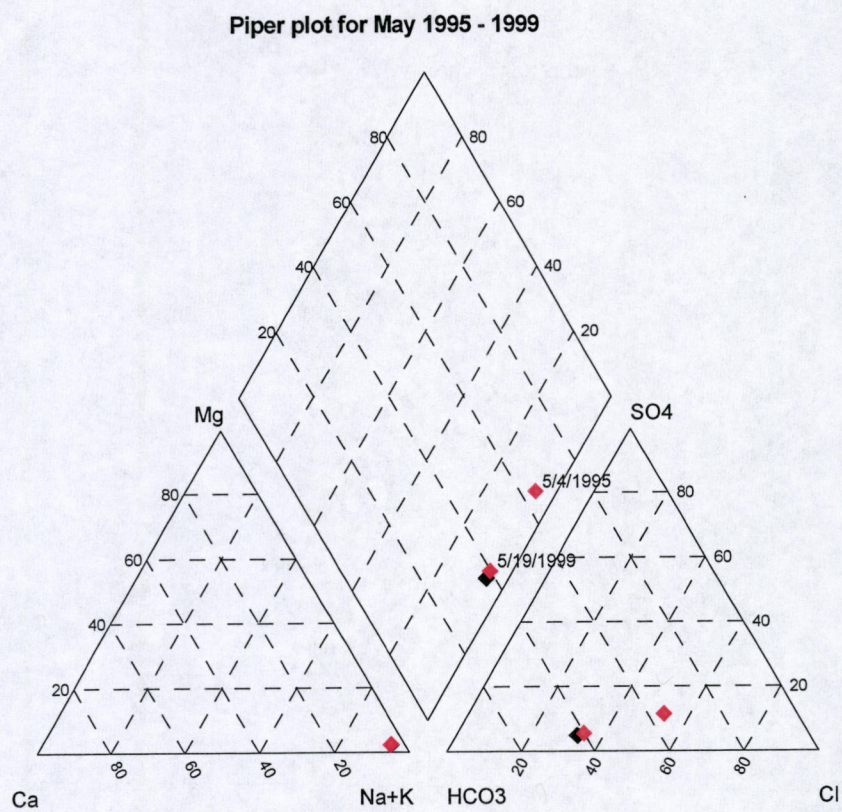
Once the change occurred in 1991, the time series plot showed fluctuations within the increased concentration of Na-Cl ions. Considering ground water recharge as a control, various months were plotted alone/highlighted on the piper diagram to look at any seasonal correlation.



This piper diagram highlights Cl ion increasing in the mid-late 1990's, for sample data collected in August.

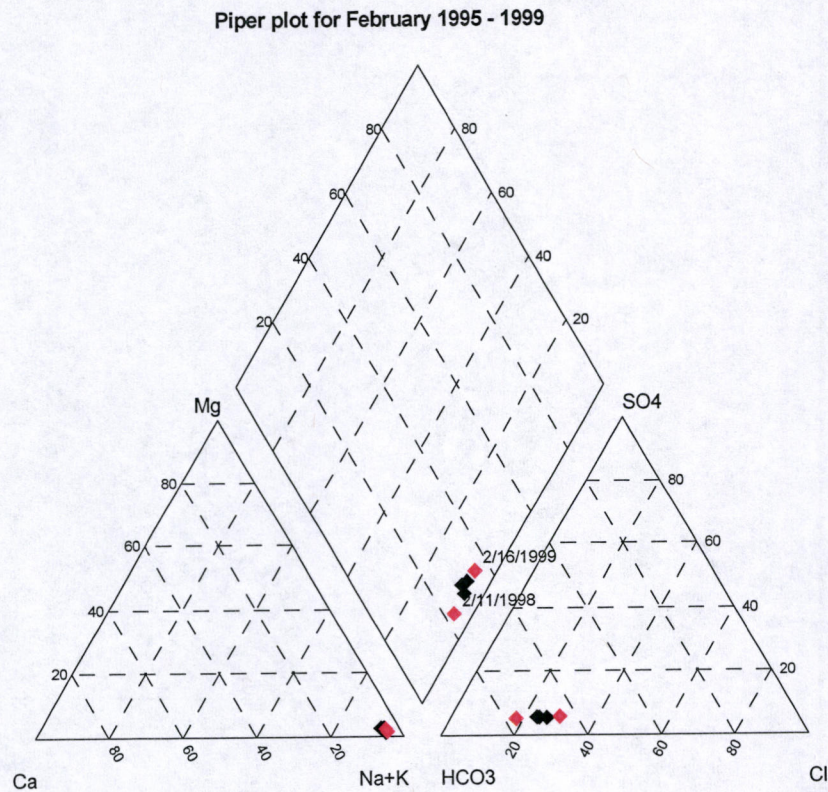


However, Cl ions are inconclusive in the late 1990's when samples from May were analyzed, due to an anomaly and a small spread otherwise.





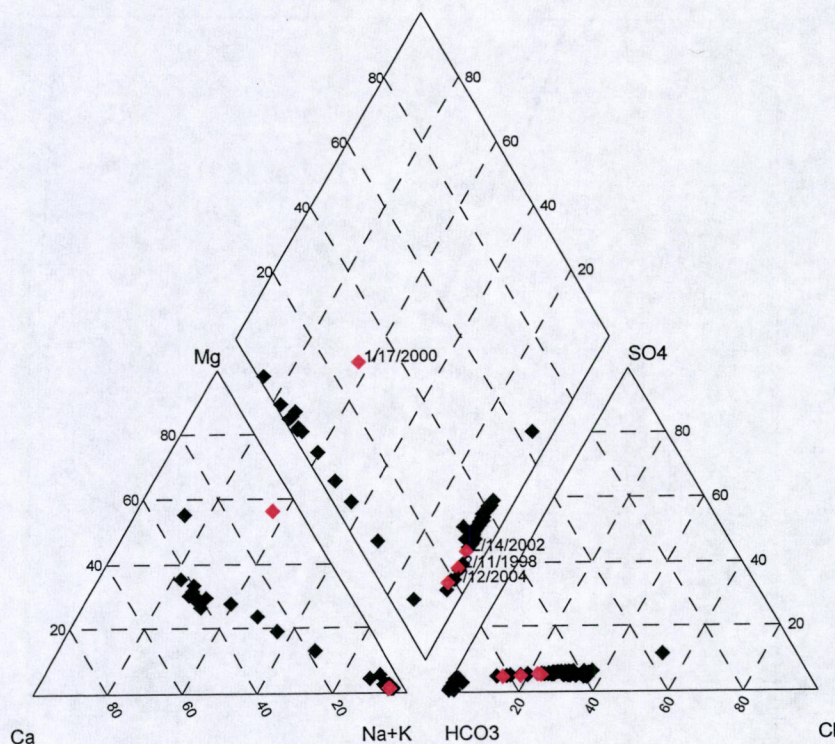
Samples taken in February also have no trend in the spread of data points.



This shows that overall there is scatter within the sample data. It may have been more conclusive with samples collected in April, when spring run off is recharging the aquifer.



Stuart Dom - Jan, Feb 98 - 04



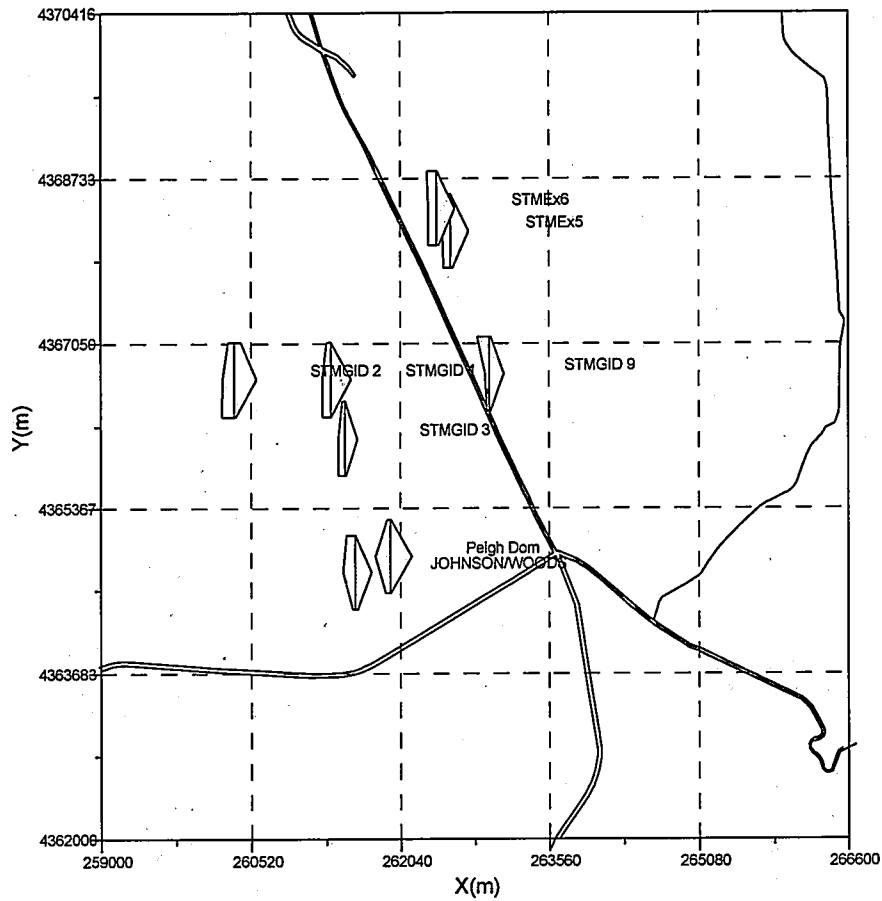
Seasonal changes are also not seen with more recent data. One may expect January and February to have more  $\text{HCO}_3$  and less  $\text{Cl}$  plotted on the diagram. Although it is possible that the winters of 2000- 2004 are not reflective due to below average precipitation and January is typically a 'dry' month, for the area. (1/17/2000 appears to be an anomaly.) Overall, the above diagrams can conclusively show the influx of Na-Cl type water into the Stuart domestic well during 1991.

### Discussion:

Thirty-one wells in South Truckee Meadows were considered in this hydrochemical study. The following relationships have been plotted using the most recent available data for each location. Scales for the Stiff diagrams varied from map to map, depending on content. Eight wells have sample data depicting drinking water and are shown below:



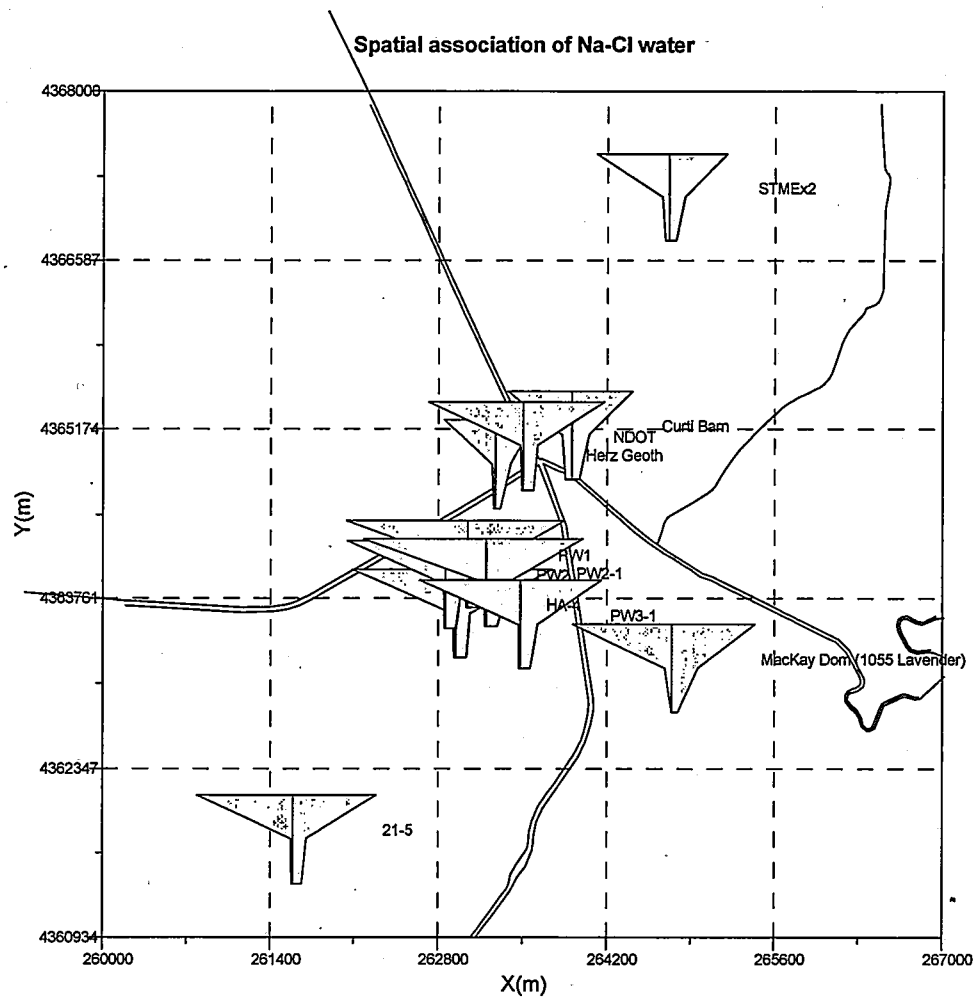
### Spatial association of alkaline water



Variations in hydrochemistry of these wells have been slight and appear to be related to ground water recharge with no evidence of geothermal water influence.



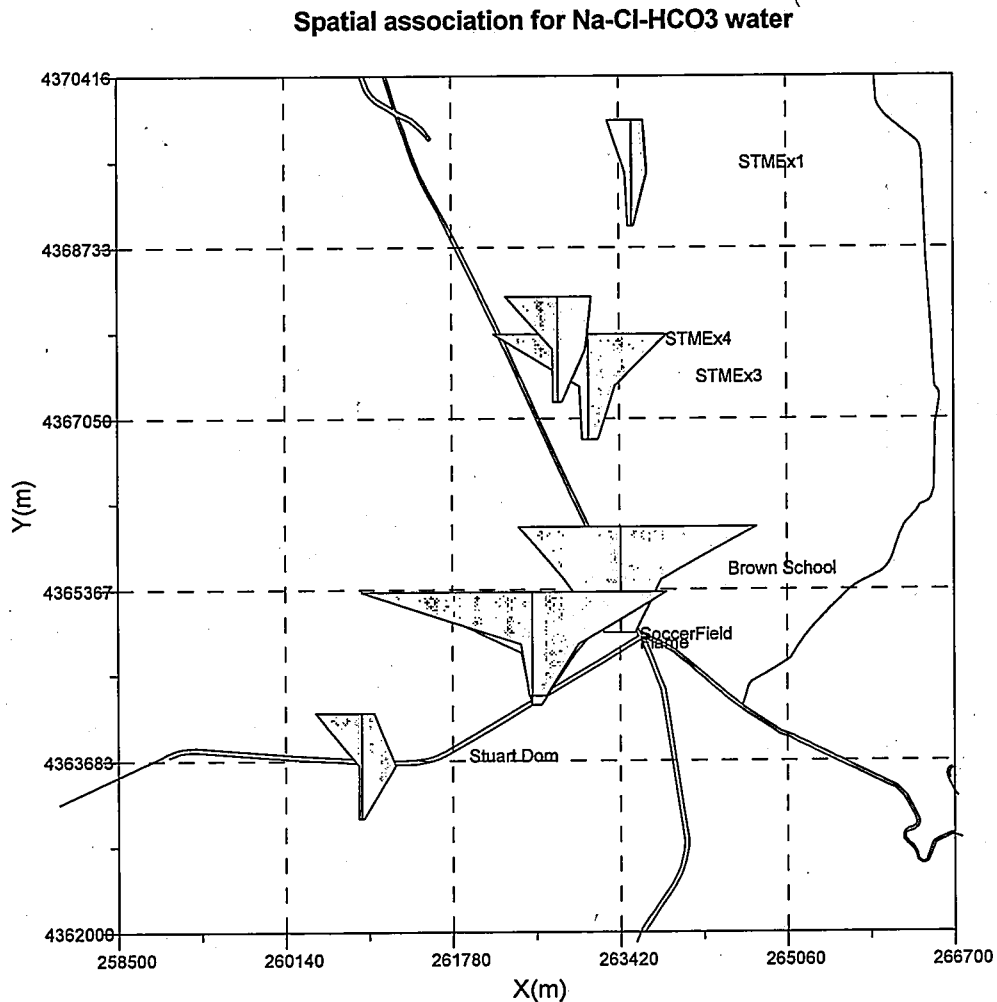
Twelve wells have clearly tapped a geothermal source, with a Na-Cl water type existing throughout their individual collection periods.



This map shows an elementary NE trend of geothermal water type, but should be studied further.



Seven wells show evidence of mixing with Na-Cl-HCO<sub>3</sub> and Na-Ca-Cl-HCO<sub>3</sub> water types. Their spatial relations are shown below:

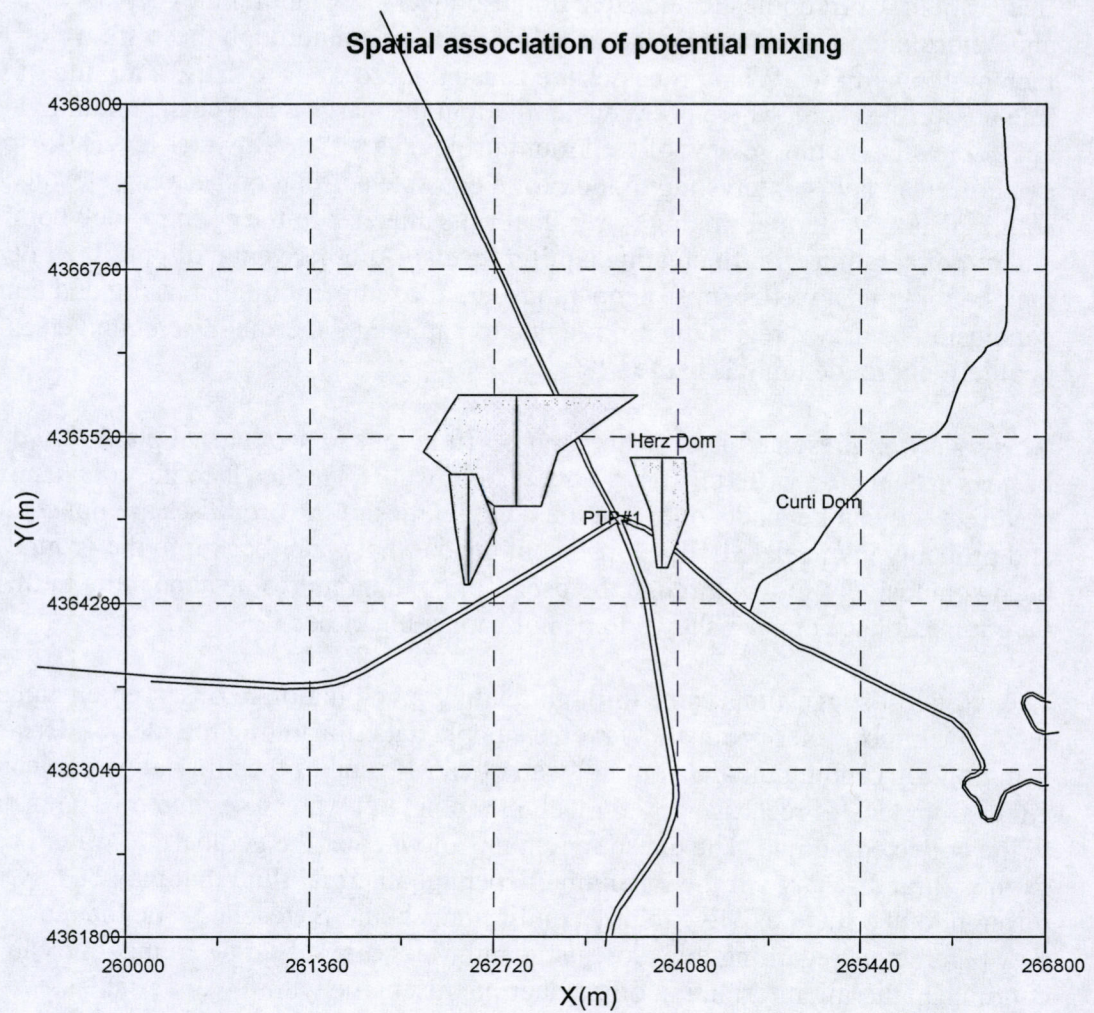


Flame and Soccer field stiff diagrams are overlapping in the above map; both are Na-Cl-HCO<sub>3</sub> water type.

Three wells have such varied chemistry or limited sample data that they are categorized as probable mixing of geothermal and fresh water but this study found their hydrochemical facies inconclusive of any clear trends. These three wells and their spatial



relation are shown below:



Overall, the ten wells whose chemistry contains a mix of fresh and geothermal water pose the question of what process is taking place to produce this mixture. Assuming alluvial water was initially present, a myriad of factors may be conducive for the blending of water types.



## Conclusion:

The change in hydraulics is evident for the Brown School, Stuart domestic, Flame, Soccer field, Curti domestic and Herz domestic wells: by noting the increase in sodium and chloride ions, geothermal discharge has been shown, through these six wells, to have increased over time. What processes are causing these wells to show a mixing of water? The answer lies somewhere between geothermal discharge and a change in alluvial aquifer levels. Future review of well monitoring data with well water levels (historical and current) may be interesting to look for a possible correlation between elevated ions in solution and geothermal mixing or residual salts attached to the country rock coming in and out of solution with fluctuating aquifer levels. Another venue of possible interest may be looking at well sample temperatures, is the temperature increasing and could any conclusion be drawn regarding mixing due to natural geothermal discharge verses geothermal production discharge?

No single well presented itself with strong correlations to geothermal plant start dates, besides speculation with regards to Soccer field well. This leads to the conclusion that no direct ties can be made, only that the complexities of the processes are not self evident and probably inter-related. Injecting spent geothermal water back into the ground has not been conclusively shown through the use of piper diagrams to be happening in this area. Of course, it has not been shown to be not happening either.

The strongest suggestions came through relating precipitation to observed changes in the data which most likely points toward the sample data illustrating the idea of denser fresh water on top capping the buoyant hot water beneath, and as the alluvial water decreases, either from lack of recharge or too much pumping, hot water rises and mixing is detected in the collected sample. The question remains of whether the geothermal water present is from natural discharge or the injection of spent geothermal fluid that may be traveling through fault structures. Eventually equilibrium should be reached, one that encompasses new parameters regarding drawdown and anthropogenic recharge, so that one can continue gathering information on geothermal discharge with fewer variables.



## References:

AquaChem v.4.0, 2003, Water quality data analysis, plotting and modeling computer program: Waterloo Hydrogeologic, Inc.

Drever, J.I., 1982, *The Geochemistry of Natural Waters*: Prentice Hall, Inc. Englewood Cliffs, N.J., ch. 1.

GeothermEx, Inc., 2007, A Review of Groundwater Monitoring Data and Assessment of the Potential Impact of the Galena II Project on Groundwater Adjacent to the Steamboat Springs Geothermal Area, Washoe County, Nevada: prepared for ORMAT Nevada, Inc.

White, D.E., Thompson, G.A., and Sandberg, C.H., 1964, Rocks, structure and geologic history of the Steamboat Springs thermal area, Washoe County, Nevada: U.S. Geologic Survey Prof. Paper 458-B, 63pp.

Widmer, M., 2006, Analysis of ground water level and water quality changes in the vicinity of the Steamboat Springs Geothermal Area, Washoe County, Nevada: Washoe County Department of Water Resources, Reno, Nevada.

Yeaman, Frank L., 2006, An analysis of ground water monitoring data in the Steamboat Springs Geothermal Area. Consultant report prepared for Washoe County Department of Water Resources, Reno, Nevada. 34p.