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Technical Memorandum

Date: October 30, 2000

To: Big Sandy Energy Project EIS
Hydrology Team

From: Cortney Brand, R.G.

Subject: ***Stable Isotope Sampling Results***

BACKGROUND AND PURPOSE

This memorandum presents findings and conclusions from the first round of stable isotope sampling from wells and springs in the vicinity of the Big Sandy Energy Project site. Groundwater samples were collected from five wells on the subject property, including two upper aquifer wells (OW-7 and OW-8), one middle aquifer well (OWMA-2), and two lower aquifer wells (PW-2 and OW-4). Samples were also collected from Cofer Hot Spring and a seep/spring along Sycamore Creek approximately 4 miles northeast of the project site. A total of seven samples were collected and analyzed for oxygen and hydrogen stable isotope composition.

The purpose of sampling and stable isotope analysis was to 1) assess the source(s) of recharge to the lower aquifer, and 2) evaluate whether the upper, middle, and lower aquifers are isotopically distinguishable. Information gained from this investigation will be used in combination with borehole lithologic data to construct a numerical groundwater model.

FINDINGS

Results of stable isotope analysis of groundwater and spring samples are presented in the following table. These data were plotted on $\delta^{18}O$ versus δD and $\delta^{18}O$ vs. Chloride concentration graphs to assist with interpretation (Figure 1).

Sample Point	d^{18}O (per mil)	dD (per mil)
Upper Aquifer		
OW-8	-10.6	-76
OW-7	-10.5	-77
Middle Aquifer		
OWMA-2	-10.3	-77
Lower Aquifer		
OW-4	-10.3	-75
PW-2	-10.1	-75
Springs/Seeps		
Cofer Hot Spring	-10.3	-75
Sycamore Creek	-9.3	-67

CONCLUSIONS / OBSERVATIONS

The following conclusions were developed based on analysis of the stable isotope data (Figures 1 and 2):

1. ***The Sycamore Creek seep sample is significantly enriched in ^{18}O and D in comparison with the groundwater and Cofer Hot Spring samples.*** This suggests that precipitation occurring in the vicinity of the Aquarius Cliffs, which is assumed to be the recharge source for this seep, is enriched in ^{18}O and D in comparison to the recharge source(s) for the upper, middle, and lower aquifers.

   The fact that the groundwaters are more depleted suggests a higher-elevation source than the Aquarius Cliffs to the east, which reach a maximum elevation of approximately 5,000 feet in the vicinity of Sycamore Creek. Based on the geography of the basin, the recharge areas of sufficient elevation to cause the observed stable isotope depletion are the northern portion of the Hualapai Mountains to the west and the Cottonwood Mountains to the north. Both these mountain ranges reach elevations of 7,000 feet or greater.

   The uncertainty in this conclusion is that the seasonal fluctuation in stable isotopic composition of the seep in Sycamore Creek is unknown. The sample was collected in late September, which would represent the isotopic composition of summer (monsoonal) precipitation. Precipitation occurring during the winter would likely be more depleted. Brand (1995) sampled surface waters in the Verde River watershed in August and January of 1995, and found that samples of tributaries to the Verde River collected in August were depleted in ^{18}O from 0.7 to 1.4 per mil in comparison to those collected in January.

   The only way to resolve this uncertainty would be to sample the seep in January of February of 2001.

2. ***If the upper, middle, and lower aquifers are recharged by the same higher-elevation source, then potentially the lower aquifer obtains a component of its recharge from the Aquarius Cliffs.*** This conclusion is based on the observation that the lower aquifer samples plot in between the upper aquifer and Sycamore Creek seep samples. If this represents a mixing line, then the data suggest that the lower aquifer obtains approximately 75 percent of its recharge from the same source as the upper aquifer and about 25 percent from the Aquarius Cliffs.

   This may also be supported by results from the pumping well (PW-2) sample, which was collected after 2 weeks of pumping at a rate of 2,000 gpm. Groundwater from PW-2 is 0.2 per mil enriched in ^{18}O relative to groundwater collected from OW-4 and its isotopic composition appears to migrate towards that of the Sycamore Creek seep (Figures 1 and 2). This may suggest that long-term, sustained pumping from the lower aquifer induces recharge from the east.

3. ***All of the samples collected plot below the meteoric water line.*** This suggests that either 1) all of these waters have been subjected to evaporation, 2) a local meteoric water line exists in the area, or 3) a persistent analytical error occurred.

   It is expected that the upper aquifer samples would display an evaporative signature since they likely represent surface water from the Big Sandy River that has percolated through the alluvial channel sediments. It is also possible that the Sycamore Creek seep sample could be evaporated if it represents direct precipitation onto the Aquarius Cliffs that has flowed over land before infiltrating. However, it is suspicious that both the middle and lower aquifer samples display an evaporative signature. This either suggests that these aquifers are recharged by the same source as the upper aquifer or supports the possibility that a local meteoric water line exists.

4. ***The upper, middle, and lower aquifer samples plot in distinguishable groupings***. However, more data are needed (especially from the middle aquifer) to confirm this conclusion.
5. ***The sample collected from PW-2 shows no indication of mixing with water derived from either the upper or middle aquifers.*** This supports findings from aquifer testing.
6. ***The source of Cofer Hot Spring is either the lower aquifer or the recharge source to the lower aquifer.*** The samples collected from OW-4 and Cofer Hot Spring have identical stable isotopic signatures and very similar major ion chemistry. This supports findings from aquifer testing, which suggest a hydraulic connection between the lower aquifer and Cofer Hot Spring.

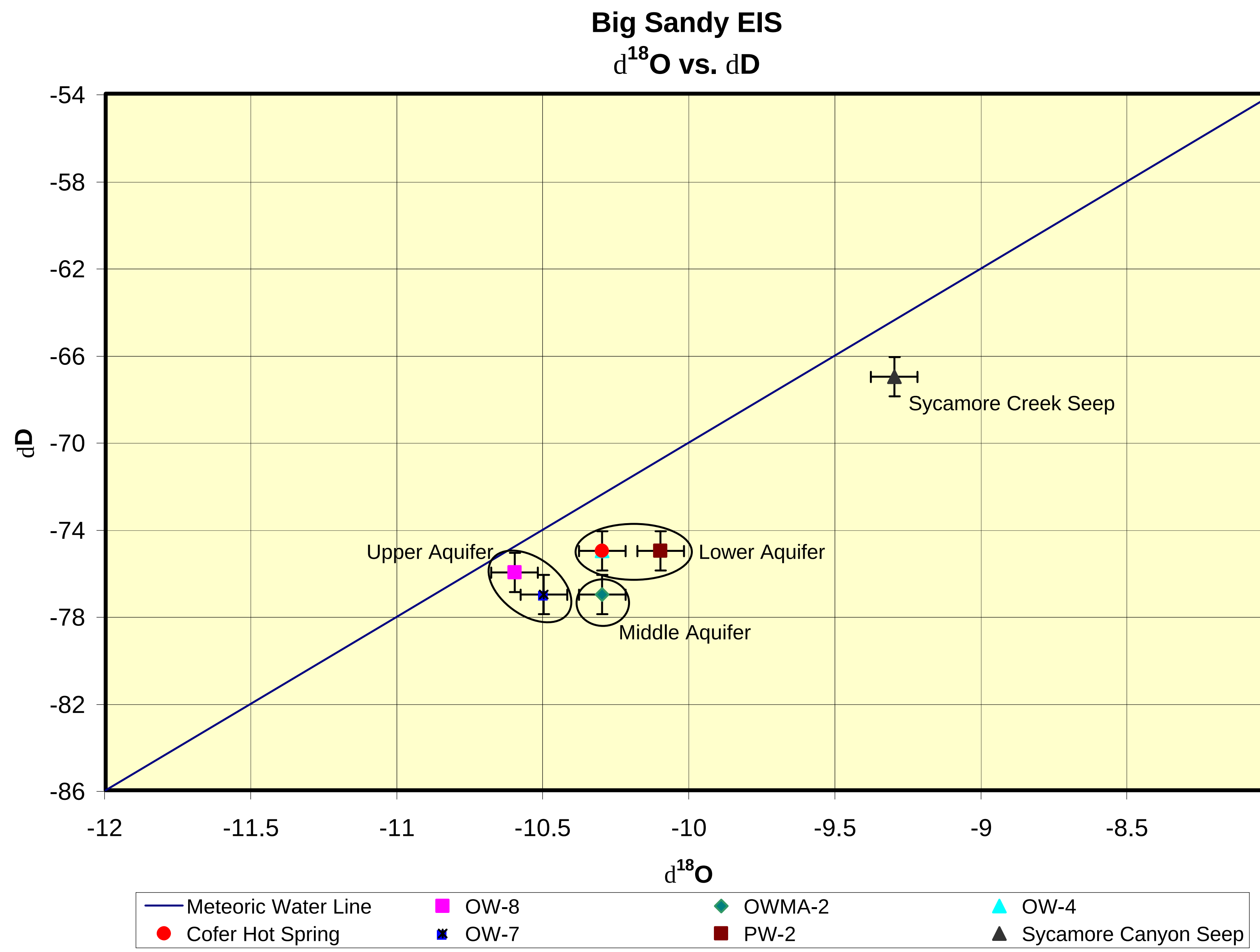
RECOMMENDATIONS

The following recommendations were developed based on findings and conclusions from the first round of stable isotope sampling.

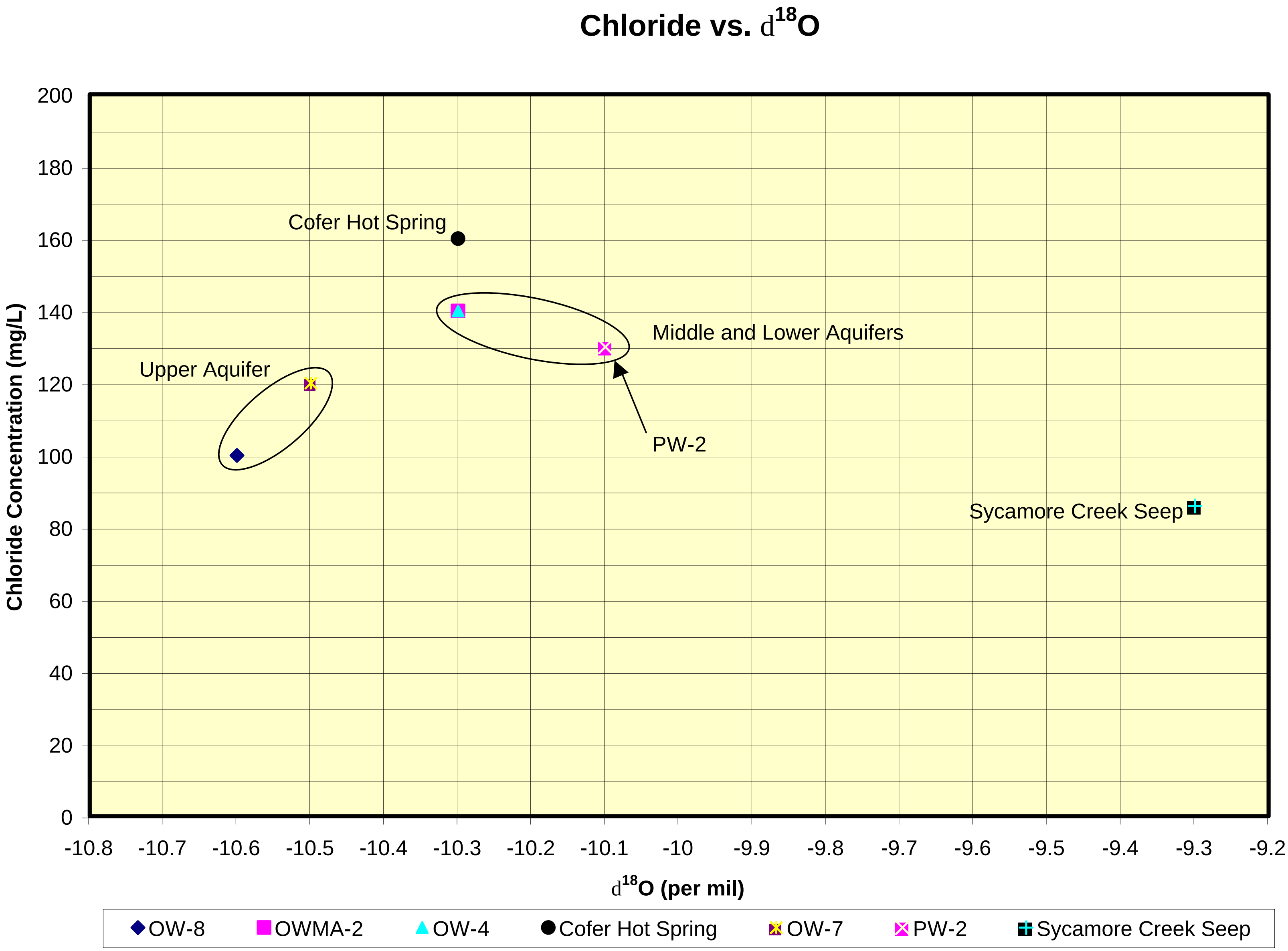
1. In order to confirm or refute the conclusions regarding recharge source(s) for the lower aquifer, it is recommended that additional samples be collected from springs/seeps and shallow wells both in the Aquarius Cliffs and in the Hualapai and/or Cottonwood Mountains.
2. It is recommended that a well be sampled that is located in the northern end of the watershed. The purpose of this would be to compare the stable isotopic composition of groundwater in the northern portion of the basin with that in the southern portion. This information will also be useful in combination with sample results from springs/seeps in the Hualapai and/or Cottonwood Mountains.
3. In order to assess the seasonal fluctuation in stable isotopic composition of recharge to the Aquarius Cliffs, it is recommended that the same springs/seeps and shallow wells be sampled in January or February of 2001. However, the project schedule makes this impractical.

REFERENCES

Brand, C. C., 1995, Evolution of Surface Water in Central and Southern Arizona Using Hydrogen and Oxygen Isotopic Analysis.



Big Sandy EIS
d18O vs. dD
-54
-58
-62
-66
-70
-74
-78
-82
-86
dD
-12
-11.5
-11
-10.5
-10
-9.5
-9
-8.5
-8
d18O
Sycamore Creek Seep
Upper Aquifer
Lower Aquifer
Middle Aquifer
Meteoric Water Line
OW-8
OWMA-2
OW-4
Cofer Hot Spring
OW-7
PW-2
Sycamore Canyon Seep



Chloride vs. d18O
Chloride Concentration (mg/L)
200
180
160
140
120
100
80
60
40
20
0
-10.8
-10.7
-10.6
-10.5
-10.4
-10.3
-10.2
-10.1
-10
-9.9
-9.8
-9.7
-9.6
-9.5
-9.4
-9.3
-9.2
d18O (per mil)
Cofer Hot Spring
Middle and Lower Aquifers
Upper Aquifer
PW-2
Sycamore Creek Seep
OW-8
OWMA-2
OW-4
Cofer Hot Spring
OW-7
PW-2
Sycamore Creek Seep

URS

Technical Memorandum

Date: December 15, 2000

To: Big Sandy Energy Project EIS
Hydrology Team

From: Cortney Brand, R.G.

Subject: ***Stable Isotope Sampling Results (Second Round)***

BACKGROUND AND PURPOSE

This memorandum presents findings and conclusions from the second round of stable isotope sampling. Three springs were sampled in the Aquarius Cliffs to the northeast of the subject property, including Arrowweed, Deer, and Halo. Samples were also collected from two springs in the Hualapai Mountains to the northwest of the subject property, including Wild Cow and Chappo. A total of five samples were collected and analyzed for oxygen and hydrogen stable isotope composition, and selected metals and inorganics including calcium, magnesium, potassium, sodium, fluoride, total dissolved solids (TDS), and alkalinity.

The primary purpose of the second round of sampling and stable isotope analysis was to better assess the source(s) of recharge to the lower (volcanic) aquifer. Findings from the first round of sampling, which included on-site wells, Cofer Hot Spring, and a seep along Sycamore Creek, suggested that the Aquarius Cliffs might not be the primary recharge area for the lower aquifer. This preliminary conclusion was based on the relatively different stable isotopic signatures of the lower aquifer groundwater samples (OW-4 and PW-2) and the Sycamore Creek seep sample, which was collected in the Aquarius Cliffs approximately 4 miles northeast of the subject property.

It was proposed that the primary recharge area to the lower aquifer might be from a higher elevation source, such as the Hualapai Mountains. However, it was also noted that precipitation in the vicinity of the Aquarius Cliffs could be 0.7 to 1.4 per mil more depleted in ^{18}O during the winter. If so, then the stable isotopic signature of springs in the Aquarius Cliffs would be similar to that of the lower aquifer. In order to resolve this uncertainty, it was decided that springs in the Aquarius Cliffs and Hualapai Mountains would be sampled to compare their stable isotopic compositions.

FINDINGS

Results of stable isotope analysis of spring samples from the Aquarius Cliffs and Hualapai Mountains are presented in the following table. These data were plotted on $\delta^{18}O$ vs. δD (Figure 1) and $\delta^{18}O$ vs. chloride concentration (Figure 2) graphs along with the samples collected during the first round to assist with interpretation.

Sample Point	d^{18}O (per mil)	dD (per mil)
Aquarius Cliffs		
Arrowweed Spring	-9.9	-70
Deer Spring	-10	-71
Halo Spring	-9.8	-69
Hualapai Mountains		
Wild Cow Spring	-11.1	-77
Chappo Spring	-11.2	-80

CONCLUSIONS

The following conclusions were developed based on analysis of the second round of stable isotope data (refer to Figures 1 and 2):

1. ***The Aquarius Cliffs are likely the primary recharge source to the lower aquifer.*** The springs sampled in the Aquarius Cliffs during the second round (November 30, 2000) are approximately 0.6 per mil more depleted in ^{18}O than the Sycamore Creek seep sample, which was collected on September 15, 2000. This suggests that precipitation on the Aquarius Cliffs is becoming more representative of winter precipitation, which is more depleted in ^{18}O and Deuterium (D). Findings from Brand (1995) indicate that tributaries to the Verde River can be 0.7 to 1.4 per mil depleted in ^{18}O during the winter relative to the summer. Thus, it is likely that the Aquarius Cliffs springs will become more depleted in ^{18}O and D by January/February of 2001 and have a similar stable isotopic signature to the lower aquifer. This is also supported by the similar chloride concentrations of the Aquarius Cliffs springs and the lower aquifer groundwater samples.

   In contrast, the Hualapai Mountains springs are significantly depleted in ^{18}O (approximately 1.0 per mil) relative to the lower aquifer samples and have a much lower chloride concentration. It is likely that these springs will be even more depleted in ^{18}O by January/February of 2001. This suggests that the Hualapai Mountains are not a significant recharge source to the lower aquifer.

2. ***The lower aquifer likely receives a majority of its recharge from winter storms.*** This conclusion is based on the anticipation that the Aquarius Cliffs springs will have a similar stable isotopic signature as the lower aquifer by January/February of 2001. Most summer (monsoon) storms that occur within the Basin and Range Province of Arizona are of high magnitude and short duration. A majority of precipitation that reaches the ground typically runs off into nearby washes or streams, and does not have the opportunity to percolate into the subsurface. Whereas, winter storms are generally of lower magnitude and longer duration, and more precipitation occurs as snow in areas such as the Aquarius Cliffs and Hualapai Mountains. These types of storms allow for deep percolation or precipitation to groundwater.

3. ***The upper aquifer likely receives a component of its recharge from the Hualapai Mountains.*** The upper aquifer samples collected from OW-7 and OW-8 during the first round are approximately 0.4 per mil depleted in ^{18}O compared to the lower aquifer samples. This suggests that the upper

aquifer receives a component of its recharge from a higher elevation source such as the Hualapai Mountains and/or the Cottonwood Mountains at the north end of the Big Sandy basin.

REFERENCES

Brand, C.C., 1995, Evolution of Surface Water in Central and Southern Arizona Using Hydrogen and Oxygen Isotopic Analysis.

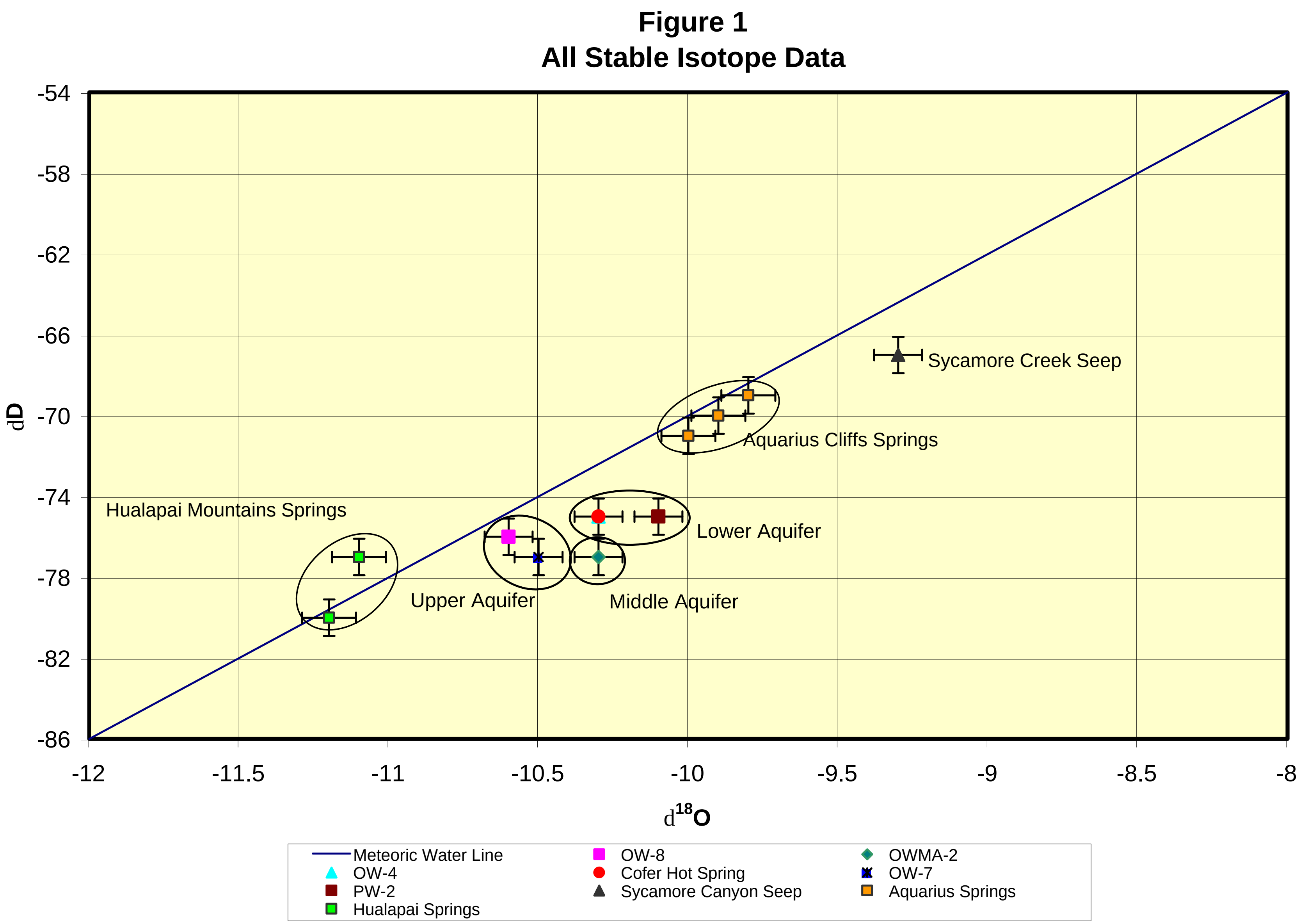


Figure 1
All Stable Isotope Data
dD
d18O
-54
-58
-62
-66
-70
-74
-78
-82
-86
-12
-11.5
-11
-10.5
-10
-9.5
-9
-8.5
-8
Sycamore Creek Seep
Aquarius Cliffs Springs
Hualapai Mountains Springs
Lower Aquifer
Upper Aquifer
Middle Aquifer
Meteoric Water Line
OW-4
PW-2
Hualapai Springs
OW-8
Cofer Hot Spring
Sycamore Canyon Seep
OWMA-2
OW-7
Aquarius Springs

Figure 2
Chloride vs. d18O