PROCEEDINGS, 46th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 15-17, 2021
SGP-TR-218

A History of Tracer Studies of the East Flank Area of the Coso Geothermal Field

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Keywords: Tracer, Injection, Coso, East Flank, Enthalpy, Steam Fraction, Interconnectivity

ABSTRACT

Multiple Tracer Studies of the East Flank Area of the Coso Geothermal Field have been done in the last two decades comparisons of several tests and wells with multiple tests indicate returns from 2 days to 2 months, with an average of 5 weeks for returns to production wells. The East Flank currently has four injection wells, 56-16, 34-9, 34B-9 and 64A-16 that handle 1000kph of fluid. There are twelve two-phase production wells. Residual tracer can be found in production wells 2 years after the addition of tracer with a base line increase of 2-5 ppb. Virtually all the tracer studies are brine phase tracers. The brine phase tracers are Naphthalene Sulfonates developed by EGI. Fluid injection pressures do not exceed 250 psi. East Flank injection wells are not stepped out, they are in close proximity to the production wells. Therefore connectivity studies have been made to estimate injection well to production well interconnectivity and response.

1. INTRODUCTION

Over a thirty year time frame twenty five tracer studies have been done on the East Flank Area of the Coso Geothermal Field. Almost all of the tests have been liquid phase tracer tests. Initial tracers tests were short in duration using Fluorescein to determine if break through was returning to production wells too fast. During the early 1990's tests from three 13-16 injection wells and the 86-17 injection well had no returns in the East Flank and little useable information. Not until 2001 with the introduction of naphthalene sulfonates as tracer and their injection in to wells that interconnected with the reservoir was any meaningful data obtained. In house naphthalene sulfonate analysis coincided with tracer tests in 34-9RD2 (11/2/01), 64A-16 (11/26/01) and 83-16 (7/24/02) started with- in 6 months of each other. EGI developed both the naphthalene sulfonate tracer and the method of analysis. Coso adapted the EGI method and it has been in use for the last twenty years. East Flank injection wells are in close proximity to the production wells, studies show fast returns for wells closest to injection, less than three weeks, in virtually all the tests. Tracer studies repeat themselves over a large time span for those wells in the North and South but vary for those wells in the middle of the East Flank.

2. MONITORING AND COMPARISON

Major tracer studies have been done as a group of injectors, first in wells 64A-16, 83-16, and 34A-9 from November of 2001 to July of 2002, then another large multi-well injection study was done for injection wells 64A-16, 56-16, and 34B-9 in March of 2012, a single well injection study in well 56-16 in September of 2020, results for the 2020 test are in Table 1. Minor Tracer studies have been done on injection wells 34A-9, 51B-16, and 64-16. An EGS tracer study was done by EGI in 2005 that included a vapor phase tracer, propanol, in well 34A-9 the vapor phase tracer did have returns in well 38C-9, 38D-9, and 38B-9, see Figure 1. There are two major injection areas in the northern part of East Flank with wells 34-9RD2, 34A-9 (abandoned), and 34B-9 forked well, and in the southern area 64A-16, 83-16(no longer used) and 56-16. Currently 56-16 takes the most fluid with a rate of 400-600kph. In the middle of East Flank, injection into 51B-16 was brief 1-2 years, and for well 64-16 it was used for injection for just 2 months before it went back to production well service. Injection into the southern injection wells have fast returns less than 3 weeks for production wells 83A-16, 64-16, 83B-16, and for the 2020 tracer study 51-16 also had fast returns and a brine phase to test. Production well 51-16 has one of the highest steam fractions on the East Flank, see Figure 6. During part of the 2012 tracer study 51-16 was dry and did not have a liquid phase, so no liquid phase tracer was tested. It is still unknown if 51-16 is dry from a shallow completion or is part of the enthalpy cycle that shown in Figure 3. Wells 51-16, 38-9 and 26A-9 have the highest steam fraction on the East Flank as shown in Figure 6. Tracer from 56-16 was more prominent in 42 and 38 pad wells in the 2012 test compared to the 2020 test see Figure 2. Both tests indicate returns in 50 days. The injection flow rate for 56-16 in the 2012 test was around 300kph, and for the 2020 test it was around 550kph. Compared to 83-16 wells there is a lower concentrations of tracer in 42 and 38 pad wells indicate mixing with up-flow before moving north from 56-16. Also crossing a fault boundary at a shallow depth may play a role as depicted by the 64-16 mini tracer study, see Figure 1. Some recycling of tracer from 34-9 pad from northern wells does contribute to 38-9 pad tracer results more so in 2020 than in 2012, this concentration would be included as part of the returns from 56-16, a southern well. Tracer from northern wells 34-9 pad injection return to 38-9 pad as fast as six days in some cases. The strong returns to 38-9 pad tracer from 34-9 injection were evident in all tracer tests in that area, but less so for 42 pad wells. In 2012 from injection well 56-16, 42A-16 and 42B-16 had strong returns, but not as much for the 2020 test. Wells in the 42-16 pad area are close to the up-flow zone in the middle of the East Flank and mixing of fluids before entering the well bore may be part of the reason for similar arrival times to the north. The fluids that are part of the up-flow area near 51-16 and 42-16 pads contain a component that suggests some younger fluids as indicated by high calcium, Powell 2013 Geochemistry Review.

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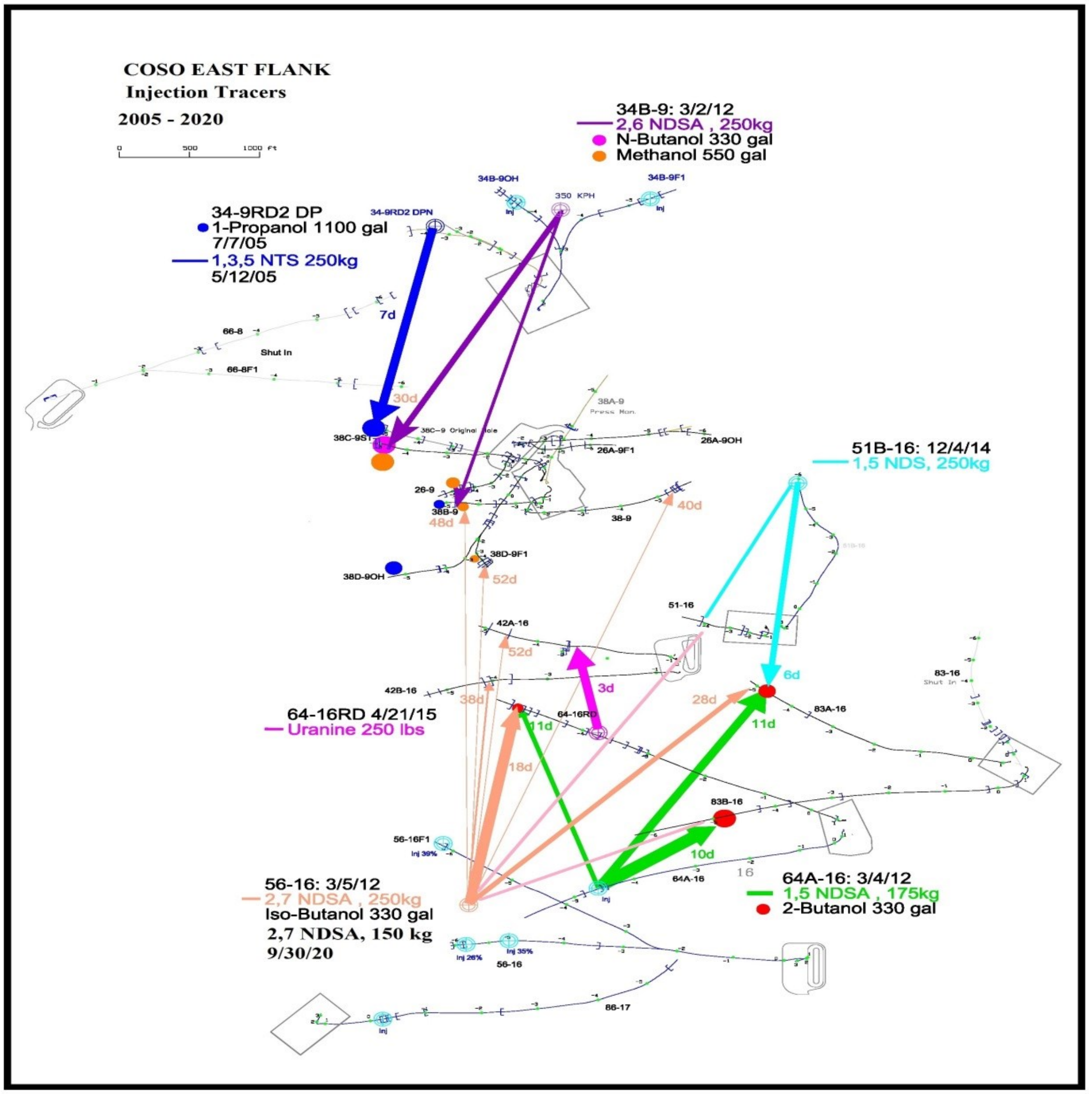

Figure 1: Map of East Flank Tracer Studies.

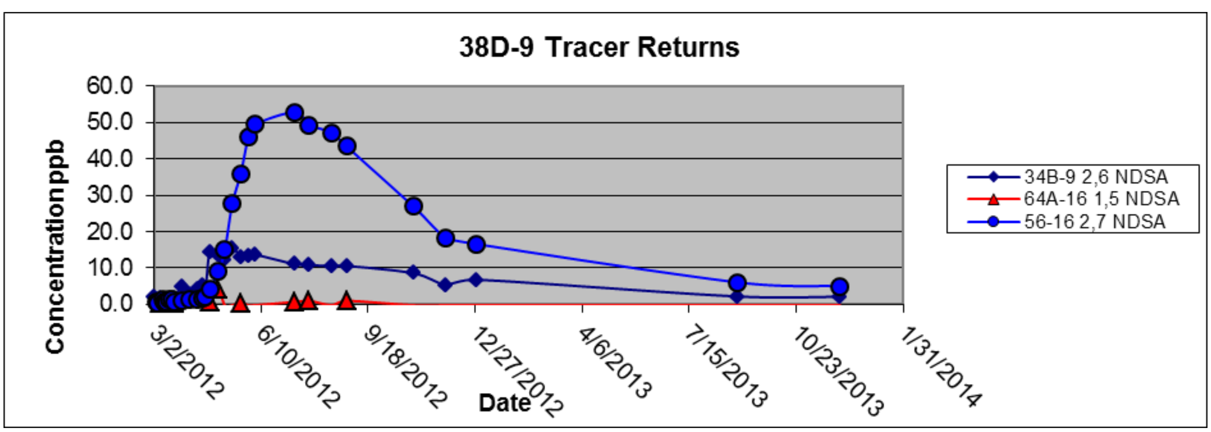

Figure 2: 38D-9 Tracer Results 2012 Tracer study. Strong Returns from 56-16 in 2012 are not as strong in 2020. Residual Tracer of 2-3 ppb can be used to calculate reservoir size.

3. EAST FLANK ENTHALPY

Well 38C-9 was graphed with the results over 15 years of enthalpy testing with a cycle occurring every 2-3 years, see Figure 3. The trend is that as enthalpy increases total flow decreases. The least mixing of East Flank fluids diagramed by Christenson 2005 was 38C-9, and the least boiling at the time was well 38C-9and 38D-9. The lower flash fraction for 38-9 pad except for well 38-9 is graphed in Figure 6, Geologica 2018 Annual Report. Areas of the lowest steam fraction are directly adjacent to areas with the highest steam fraction such a large difference shows a fault boundary from east to west. Both 38C-9 and 38D-9 have a slightly different isotopic signature that suggests some contribution from the Sierra's, Christenson 2005. Along with the strong returns from injection leads to a higher liquid component and thus the lower steam fraction for 38C-9 and 38D-9. With up-flow to the north and south of 38-9 and the higher enthalpy and steam fraction the total flow is not nearly as high as 38C-9 and 38D-9. The up-flow itself does not have to be single phase. Those fluids that have a more magmatic signature suggest added heat from a magmatic source in this particular area of highest steam fraction. The addition of a deeper steam influence initially was termed "exotic steam" that meant steam added to the steam from flashed brine near the well bore and in the well bore itself. Christenson (2005) referred to it as excess vapor fraction. The variations in flash fraction is partly due to the additional flow and heat added from this deeper source.

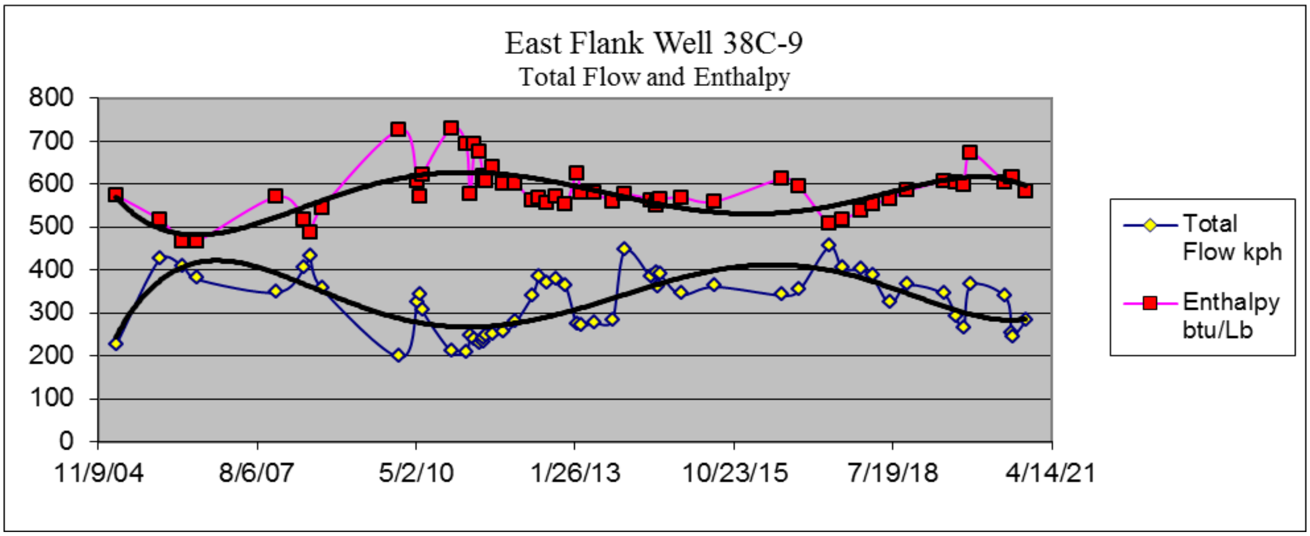

Figure 3: 38C-9 Enthalpy and Total Flow, 2005 to 2020.

4. CONNECTIVITY

As pressures drop in the East Flank wells with more interconnectivity have a higher rate of recharge. Interconnectivity studies by Horne in 2016, and also graphed in 2018 show areas of greatest injection well to production well interaction statistically as shown in both Figure 4 and 5. Clearly with fast tracer returns to wells like 38C-9 and 83A-16 the interconnectivity is large, but how the number of different flow streams and up-flow plus natural recharge interact over time and across fault boundaries is more complex and a statistical modelling approach can be helpful and needed. Tracer tests indicate when fluids are crossing fault boundaries, such as 64-16 mini tracer study, and when they cannot, interconnectivity diagrams show a difference over just two years, a cycle that is similar with enthalpy testing, see Figure 3. The wells with the highest flash fraction 51-16, 38-9, 26A-9 shown in Figure 6, all flash into the reservoir , estimates are above 40%. For 38C-9 and 38D-9 it takes the enthalpy to be above 650btu/pound before reservoir flash is calculated using silica geo-thermometer and the measured enthalpy. For 38C-9 graphed in Figure 3 the reservoir flash in 2010 calculates to 10-15%.

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5. CONCLUSION

The use of Tracers to monitor injection flow returns to production wells over the last 20 years has shown that each test is slightly different but that the trends are similar. Production wells that are closest to the injector often have the greatest returns as expected but changes between tests such as the lack of tracer in 83B-16 from 56-16 in 2012 but the large amount of tracer returns in the 2020 Tracer Study, See Table 1. 2020 data. A larger flow rate into 64A-16 in 2012 compared with 2020 is more than likely the cause. The mixing changes over many years, currently 56-16 has the highest injection flow rate on the East Flank. Up-flow at well 51A-16 was strong enough to keep injection flow streams from entering the well bore, there were no tracer results for the 2001 tracer tests. It took 12 years for the wellhead pressure at 51A-16 to drop to line pressure. The compartmentalization that was strong in early production has given way to more interconnectivity between wells were up-flow itself is not as much of a barrier. Acid jobs often positively influence the well adjacent to the well receiving the acid. All wells on the East Flank can flash into the reservoir and have at some point in the last 20 years. The higher reservoir flash leads to lower total flow rates. Well 56-16 was drilled and forked and has a higher injection rate to help maintain a balance in the reservoir flash. Interconnectivity studies have shown changes in just two years on the East Flank partly from a change in injection sources, see Figures 4 and 5. Future statistical modeling will hope-fully help in the understanding of fluid mixing and the variable flash fraction.

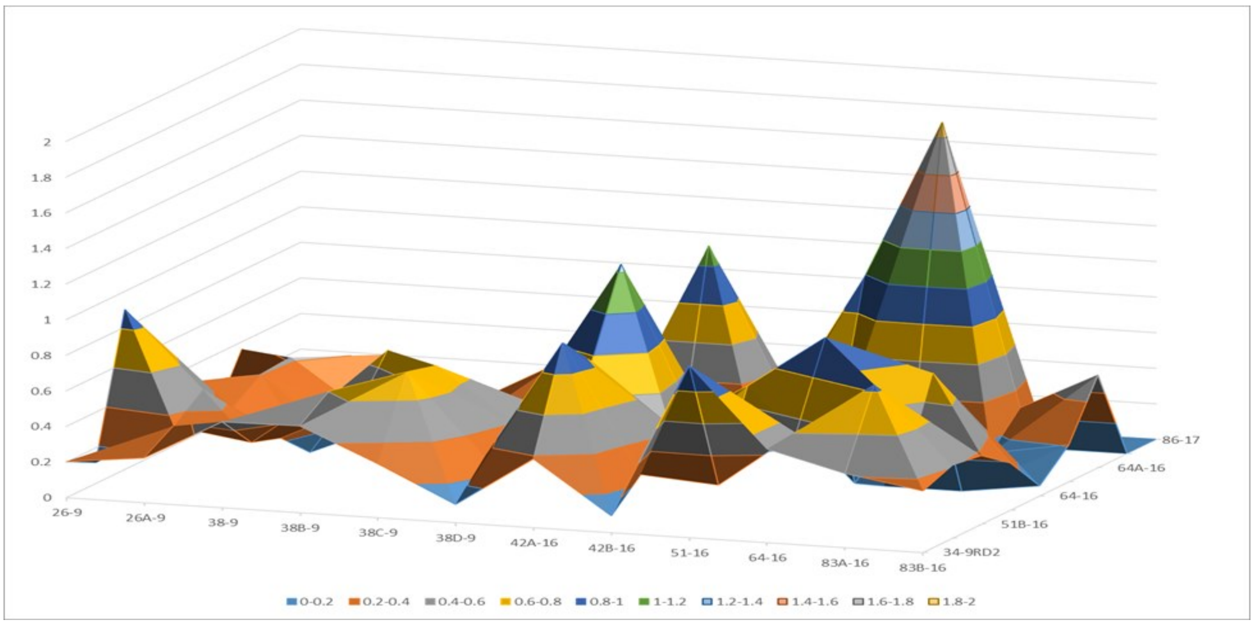

Figure 4: East Flank Connectivity Diagram, Horne 2016 Internal Report.

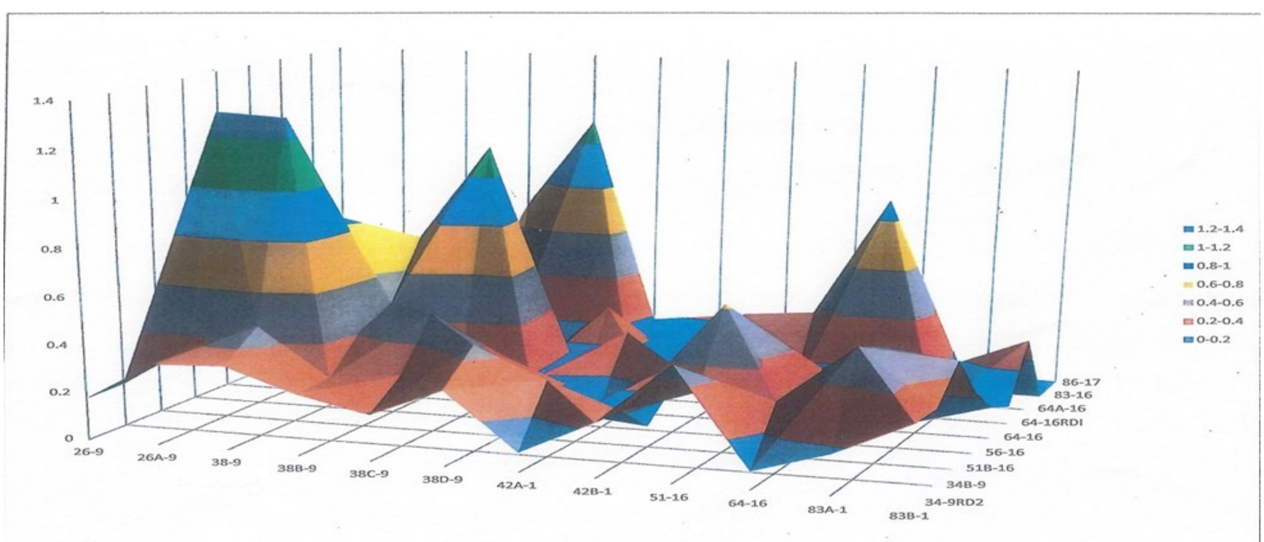

Figure 5: East Flank Connectivity Diagram, Horne 2018 Internal Report.

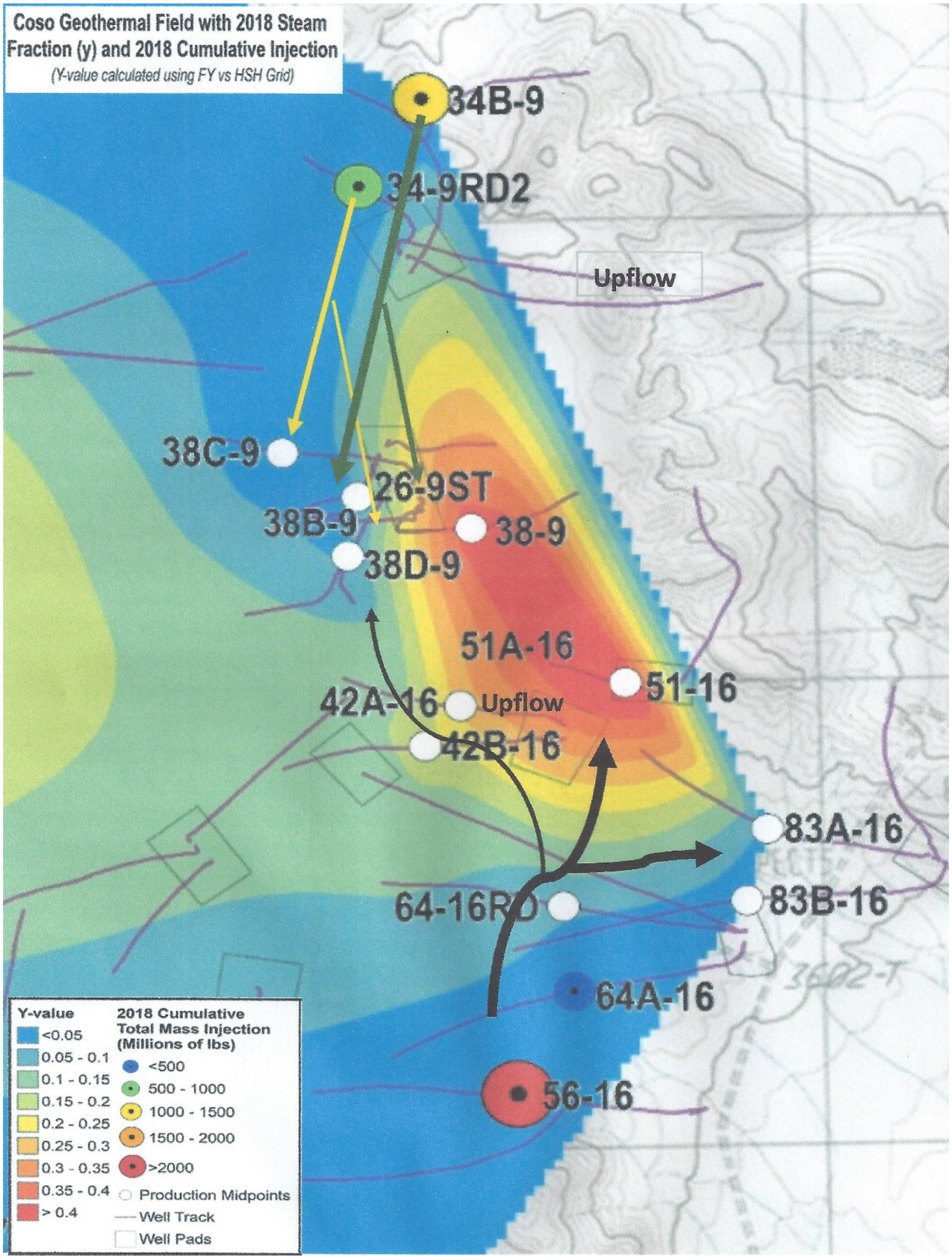

Figure 6: East Flank Steam Fraction 2018 from Geologica 2018 Annual Geochemistry Report. With Overlay of Tracer path.

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	56-16 Tracer Study 2020							
	Started on 9/30/20 added to injection 12:36 to 13:30							
	200 gallons of Approximately 5 % solution with a total of 150 Kgof 2,7 NDSA							
Production	**Sample**	**2,7 NDSA**	**Production**	**Sample**	**2,7 NDSA**	**Production**	**Sample**	**2,7 NDSA**
Well	**Date**	**ppb**	**Well**	**Date**	**ppb**	**Well**	**Date**	**ppb**
83A-16	10/3/2020	0.1	83B-16	10/3/2020	0.1	64-16	10/3/2020	0.1
83A-16	10/7/2020	0.1	83B-16	10/5/2020	0.1	64-16	10/5/2020	0.2
83A-16	10/9/2020	0.5	83B-16	10/9/2020	0.1	64-16	10/6/2020	0.1
83A-16	10/15/2020	4.6	83B-16	10/13/2020	0.6	64-16	10/7/2020	0.1
83A-16	10/17/2020	10	83B-16	10/15/2020	0.9	64-16	10/9/2020	0.1
83A-16	10/20/2020	22.1	83B-16	10/17/2020	2.5	64-16	10/14/2020	7.6
83A-16	10/23/2020	44.7	83B-16	10/20/2020	5.5	64-16	10/15/2020	6.5
83A-16	10/29/2020	96.4	83B-16	10/23/2020	10.3	64-16	10/17/2020	11.4
83A-16	10/31/2020	124	83B-16	10/27/2020	28.1	64-16	10/20/2020	17.1
83A-16	11/3/2020	151	83B-16	10/29/2020	126	64-16	10/23/2020	23.4
83A-16	11/7/2020	142	83B-16	11/9/2020	64.5	64-16	10/27/2020	34
83A-16	11/18/2020	245	83B-16	11/18/2020	137	64-16	10/31/2020	40.9
83A-16	11/30/2020	240	83B-16	11/30/2020	189	64-16	11/3/2020	48.5
83A-16	12/21/2020	196	83B-16	12/21/2020	251	64-16	11/18/2020	54.3
83A-16	1/4/2021	202	83B-16	1/14/2021	246	64-16	11/30/2020	45.7
83A-16	1/16/2021	13.6				64-16	12/21/2020	43.6
Production	**Sample**	**2,7 NDSA**	**Production**	**Sample**	**2,7 NDSA**	64-16	1/2/2021	48.9
Well	**Date**	**ppb**	**Well**	**Date**	**ppb**	64-16	1/16/2021	49.6
38-9	10/3/2020	0.1	38C-9	10/3/2020	0.1	**Production**	**Sample**	**2,7 NDSA**
38-9	10/5/2020	0.1	38C-9	10/5/2020	0.1	**Well**	**Date**	**ppb**
38-9	10/9/2020	0.1	38C-9	10/9/2020	0.1	38D-9	10/3/2020	0.1
38-9	10/21/2020	0.1	38C-9	10/20/2020	0.1	38D-9	10/5/2020	0.1
38-9	10/23/2020	0.1	38C-9	10/23/2020	0.1	38D-9	10/9/2020	0.1
38-9	10/27/2020	0.1	38C-9	10/27/2020	0.1	38D-9	10/20/2020	0.1
38-9	11/3/2020	0.1	38C-9	10/31/2020	0.1	38D-9	10/23/2020	0.1
38-9	11/18/2020	2.8	38C-9	11/7/2020	0.1	38D-9	10/27/2020	0.1
38-9	11/30/2020	4.4	38C-9	11/18/2020	0.8	38D-9	10/31/2020	0.1
38-9	12/8/2020	5.4	38C-9	11/30/2020	1.7	38D-9	11/7/2020	0.1
38-9	12/21/2020	7.7	38C-9	12/21/2020	4.7	38D-9	11/18/2020	1.1
38-9	1/4/2021	10.9	38C-9	1/2/2021	6.1	38D-9	11/30/2020	1.0
38-9	1/14/2021	11.4	38C-9	1/14/2021	6.8	38D-9	12/8/2020	2.0
						38D-9	12/21/2020	5.0
						38D-9	1/14/2021	9.4

Production Well	Sample Date	2,7 NDSA ppb
51-16	10/3/2020	0.1
51-16	10/5/2020	0.1
51-16	10/9/2020	0.1
51-16	10/20/2020	0.1
51-16	10/23/2020	0.7
51-16	10/31/2020	0.1
51-16	11/3/2020	15
51-16	11/7/2020	29.2
51-16	11/18/2020	134
51-16	11/30/2020	141
51-16	1/14/2021	150

Production Well	Sample Date	2,7 NDSA ppb
42A-16	10/3/2020	0.1
42A-16	10/5/2020	0.1
42A-16	10/9/2020	0.1
42A-16	10/21/2020	0.1
42A-16	10/23/2020	0.1
42A-16	10/27/2020	0.1
42A-16	10/31/2020	0.1
42A-16	11/3/2020	0.1
42A-16	11/18/2020	1.2
42A-16	11/30/2020	1.1
42A-16	12/21/2020	3.5
42A-16	1/2/2021	5.2
42A-16	1/14/2021	7.7

Production Well	Sample Date	2,7 NDSA ppb
26-9	10/3/2020	0.1
26-9	10/23/2020	0.1
26-9	10/27/2020	0.1
26-9	11/7/2020	0.1
26-9	11/18/2020	0.8
26-9	11/30/2020	3.2
26-9	12/21/2020	1.6
26-9	1/14/2021	18.4

Production Well	Sample Date	2,7 NDSA ppb
42B-16	10/3/2020	0.1
42B-16	10/5/2020	0.1
42B-16	10/9/2020	0.1
42B-16	10/20/2020	0.1
42B-16	10/23/2020	0.1
42B-16	10/27/2020	0.1
42B-16	10/31/2020	0.7
42B-16	11/3/2020	0.1
42B-16	11/7/2020	0.1
42B-16	11/18/2020	0.8
42B-16	11/30/2020	5.8
42B-16	12/7/2020	1.8
42B-16	12/21/2020	8
42B-16	1/2/2021	7
42B-16	1/14/2021	8.5

Production Well	Sample Date	2,7 NDSA ppb
26A-9	10/3/2020	0.1
26A-9	10/9/2020	0.1
26A-9	10/23/2020	0.1
26A-9	10/27/2020	0.1
26A-9	10/31/2020	0.1
26A-9	11/7/2020	3.7
26A-9	11/18/2020	3.3
26A-9	11/30/2020	2.3
26A-9	12/21/2020	3.3
26A-9	1/16/2021	0.8

Injection Well	Sample Date	2,7 NDSA ppb
34B-9	10/3/2020	0.1
34B-9	10/5/2020	0.1
34B-9	10/23/2020	3.6
34B-9	10/27/2020	7.7
34B-9	10/31/2020	10.1
34B-9	11/7/2020	9.1
34B-9	11/18/2020	15.5
34B-9	11/30/2020	21.7
34B-9	12/21/2020	24.9
34B-9	1/14/2021	30.0

Injection Well	Sample Date	2,7 NDSA ppb
56-16	10/3/2020	0.1
56-16	10/9/2020	0.1
56-16	10/23/2020	2.0
56-16	10/27/2020	2.5
56-16	10/31/2020	2.3
56-16	11/30/2020	16.2
56-16	12/21/2020	20.7
56-16	1/2/2021	21.4
56-16	1/16/2021	21.5

Table 2: 56-16 Tracer Results 2020.

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