

**ELECTRONIC SUPPLEMENTARY MATERIAL – HYDROGEOLOGY JOURNAL**

**Evidence for natural attenuation of 1,4-dioxane in a glacial aquifer system**

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**Table S1.** Extraction Well Average Annual Pumping Rates (gpm)

Year	AE3	LB1	LB2	LB3	LB4	DOLPH	TW12	TW-16	TW18	TW19	TW21	TW23
2005	32	94	78	-	-	42	14	-	-	-	-	-
2006	32	94	27	47	-	53	19	-	204	-	-	-
2007	19	92	-	84	-	53	9	-	231	-	-	-
2008	15	95	-	90	-	56	2	-	240	-	-	-
2009	15	94	-	80	-	57	-	-	245	-	-	-
2010	15	93	-	74	-	55	-	-	171	-	59	-
2011	3.5	73	-	39	-	33	-	-	126	12	126	-
2012	-	59	-	39	-	20	-	-	122	72	88	-
2013	-	77	-	14	5.5	11	-	-	152	99	54	-
2014	-	-	-	-	99	11	-	5	158	96	57	-
2015	-	-	-	-	98	11	-	29	157	71	59	-
2016	-	-	-	-	100	10	-	30	155	71	57	-
2017	-	2	-	-	94	14	-	4	153	46	60	43

**Table S2.** Annual Mass of 1,4-Dioxane Removed by Extraction Wells (kg)

Year	AE3	LB1	LB2	LB3	LB4	DOLPH	TW12	TW-16	TW18	TW19	TW21	TW23
2005	5	81	143	-	-	12	2	-	-	-	-	-
2006	5	87	50	49	-	12	2	-	636	-	-	-
2007	3	94	-	93	-	11	1	-	343	-	-	-
2008	3	94	-	92	-	10	-	-	232	-	-	-
2009	3	83	-	68	-	9	-	-	162	-	-	-
2010	4	94	-	70	-	9	-	-	109	-	35	-
2011	5	76	-	41	-	5	-	-	82	21	57	-
2012	-	66	-	38	-	2	-	-	77	117	26	-
2013	-	77	-	12	10	2	-	-	96	145	14	-
2014	-	-	-	-	101	2	-	9	88	130	93	-
2015	-	-	-	-	94	3	-	52	89	99	14	-
2016	-	-	-	-	93	2	-	48	86	95	15	-
2017	-	-	-	-	87	3	-	6	182	59	21	31

**Table S3.** Lines of evidence used to evaluate 1,4-dioxane natural attenuation

Evaluation Metric	Indication
Order-of-Magnitude	Concentration reduction at individual wells
Point Attenuation Rates and Half-Lives	Time estimates for concentration reduction; First-order decay rates
Bulk Attenuation	Plume changes (expansion, contraction, stabilization)
Mass Balance	Changes in 1,4-dioxane mass storage
Spatial Moments	Changes in 1,4-dioxane mass and center of mass

**Table S4.** Observed concentrations and calculated natural attenuation metrics at individual wells during first and second half of the study period.

Wells	2005-2011					2011-2017				
	Maximum Concentration (ppb)	K <sub>point</sub> Decay Coefficient	P-values for K <sub>point</sub> Decay Coefficient	Half-Life (years)	Decay Time to 7.2 ppb (years from 1/1/1985)	Maximum Concentration (ppb)	K <sub>point</sub> Decay Coefficient	P-values for K <sub>point</sub> Decay Coefficient	Half-Life (years)	Decay Time to 7.2 ppb (years from 1/1/1985)
MW-15s*	1	-	-	-	-	11	-0.421	0.764	-1.6	33
MW-15d*	2	0.253	0.122	2.7	15	2	0.193	0.247	3.6	21
MW-30d*	1626	-0.102	<0.001	-6.8	-27	1626	0.308	<0.001	2.3	44
MW-72s*	94	0.308	<0.001	2.3	28	14	0.303	<0.001	2.3	29
MW-72d*	3598	0.018	0.099	38.5	365	3500	0.175	0.002	4.0	62
MW-79s	1174	0.109	0.208	6.4	62	805	0.050	0.541	14	113
MW-81	550	-0.101	0.009	-6.9	-18	530	0.087	0.004	8.0	76
MW-83s*	644	-0.142	0.007	4.9	-5	499	0.043	0.385	16	120
MW-84s*	859	-0.172	0.001	4.0	-2	908	0.072	0.371	9.6	92
MW-85*	2476	-0.050	0.216	-13.8	-89	2476	0.140	0.005	5.0	67
MW-88	1285	0.147	0.071	4.7	54	572	0.132	0.220	5.3	58
MW-101	497	0.017	0.489	-38.7	-204	399	0.168	0.009	4.1	50
MW-105s*	3803	0.244	0.001	2.8	47	1097	0.122	0.008	5.7	67
MW-105d*	1104	0.096	0.034	7.2	73	699	0.172	0.002	4.0	52
MW-106s*	1676	0.366	0.001	1.9	37	355	0.016	0.518	43	258
MW-108s*	2946	0.081	0.006	8.6	96	2157	0.255	0.001	2.7	46
MW-108d*	4054	0.080	0.047	8.7	100	3003	0.146	<0.001	4.7	68
MW-115	1304	0.178	0.009	3.9	52	734	0.104	0.001	6.7	71
MW-116	1215	-0.277	0.043	2.5	8	1215	0.141	0.006	4.9	60
MW-119	475	0.080	0.687	-8.6	-22	475	0.150	0.200	4.6	49
MIN	1	-0.277	-	-38.7	-204	2	-0.421	-	-1.6	21
MEAN	1469	0.060	-	1.3	30	1054	0.118	-	7.5	72
MEDIAN	1195	0.080	-	2.8	28	717	0.141	-	4.8	61
MAX	4054	0.366	-	38.5	365	3500	0.308	-	43.3	258

\* = Wells located along the central plume axis

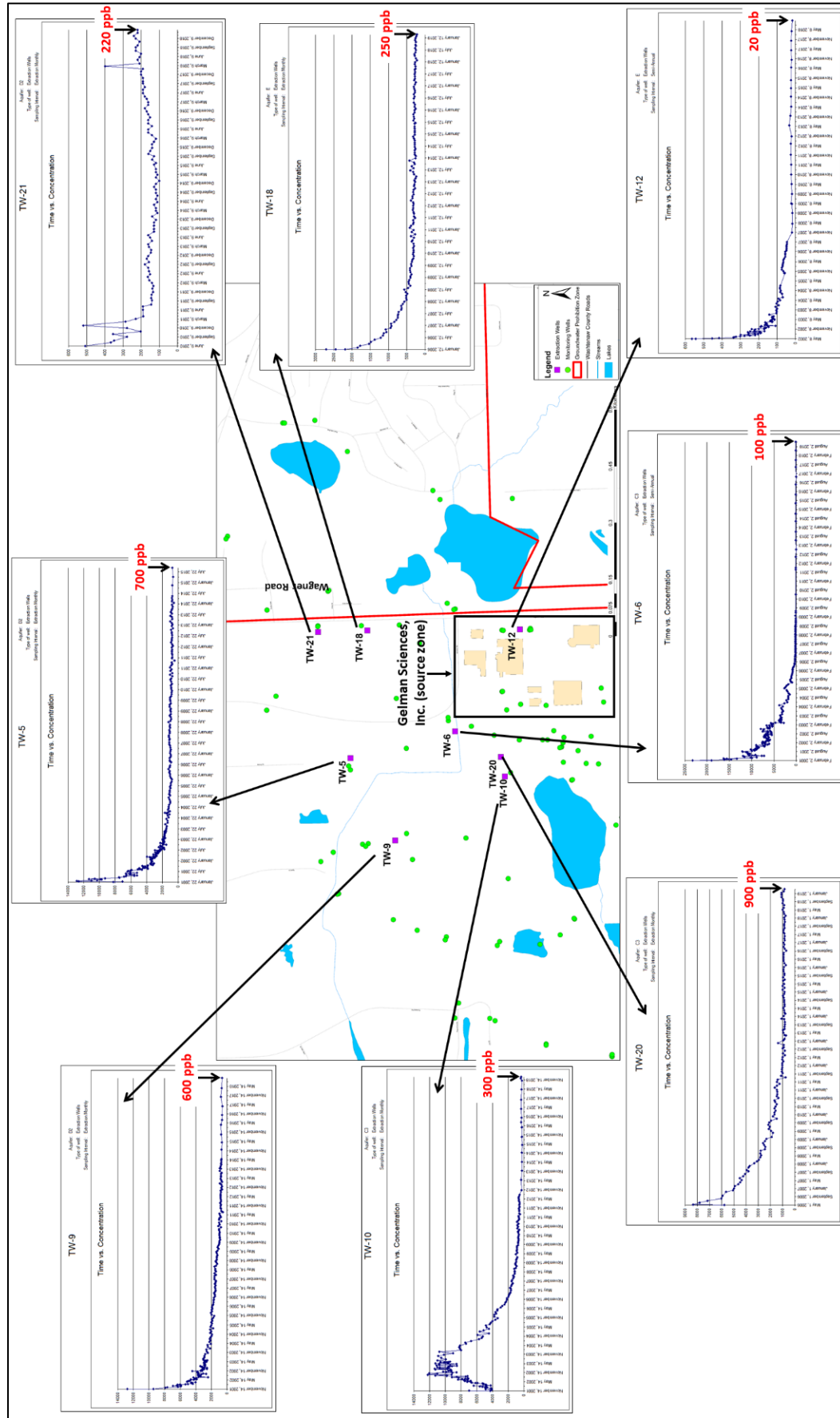
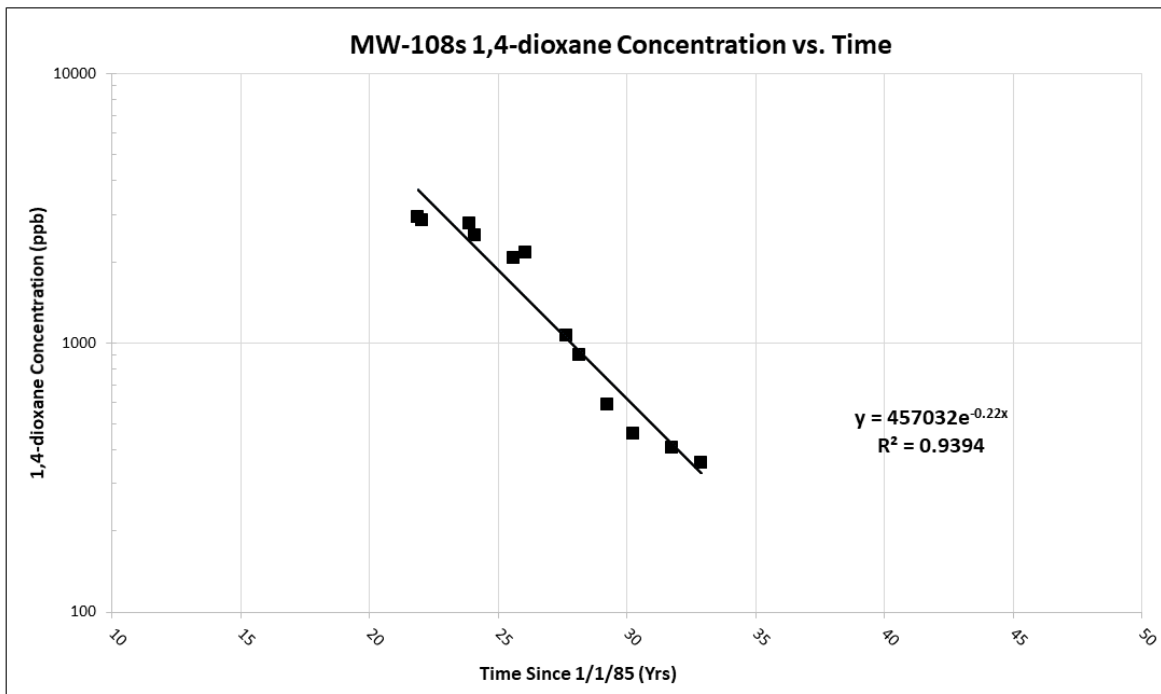
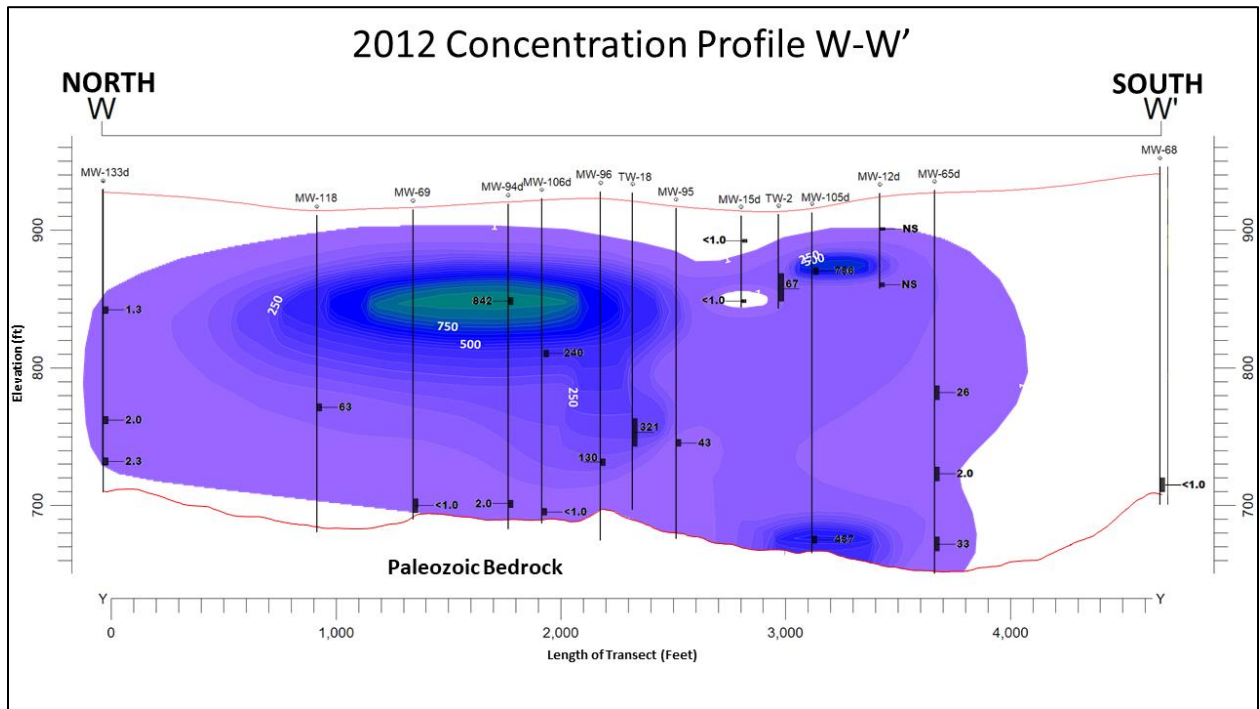


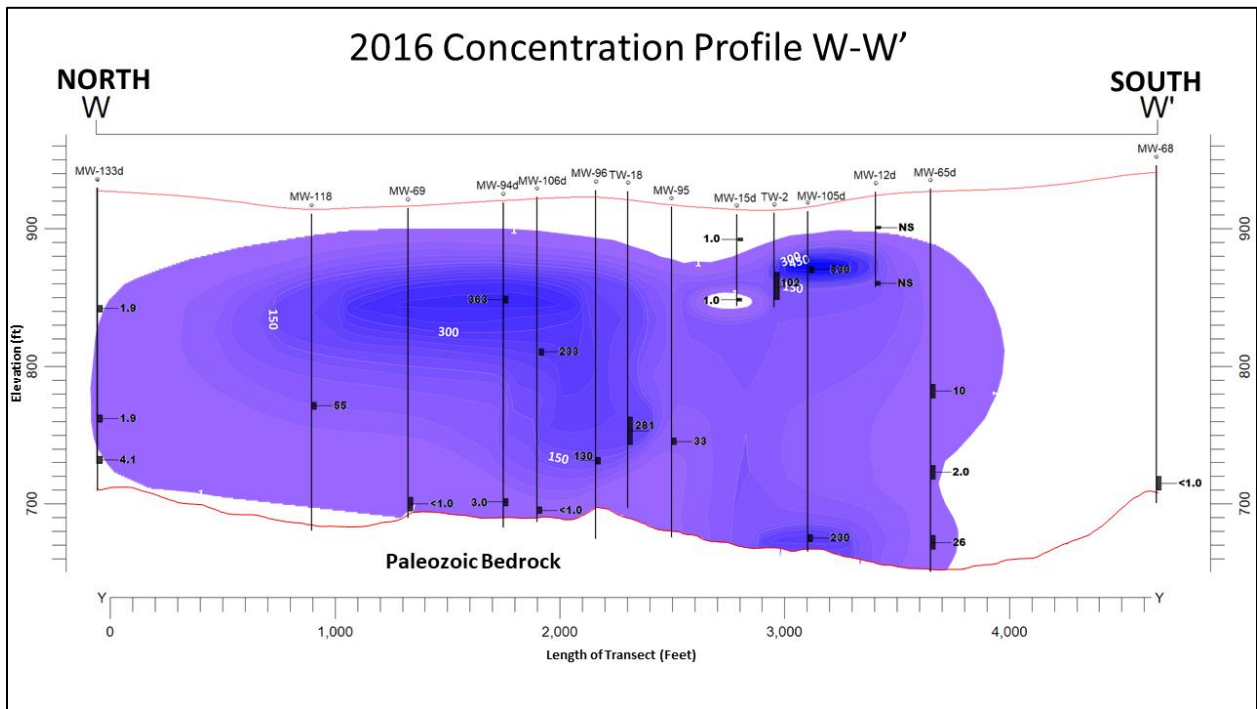
Fig. S1. 1,4-Dioxane concentration histories for extraction wells west of Wagner Road.



**Fig. S2.** Point attenuation at individual well MW-108s illustrating exponential regression. Note the *negative slope*, suggesting that attenuation is occurring because concentrations are reducing over time.



**Fig. S3.** 1,4-Dioxane concentrations used in integrated 2012 mass flux calculations. View looking down gradient.



**Fig. S4.** 1,4-Dioxane concentrations used in integrated 2016 mass flux calculations. View looking down gradient.

# 1,4-Dioxane Distribution (Eastern Area)

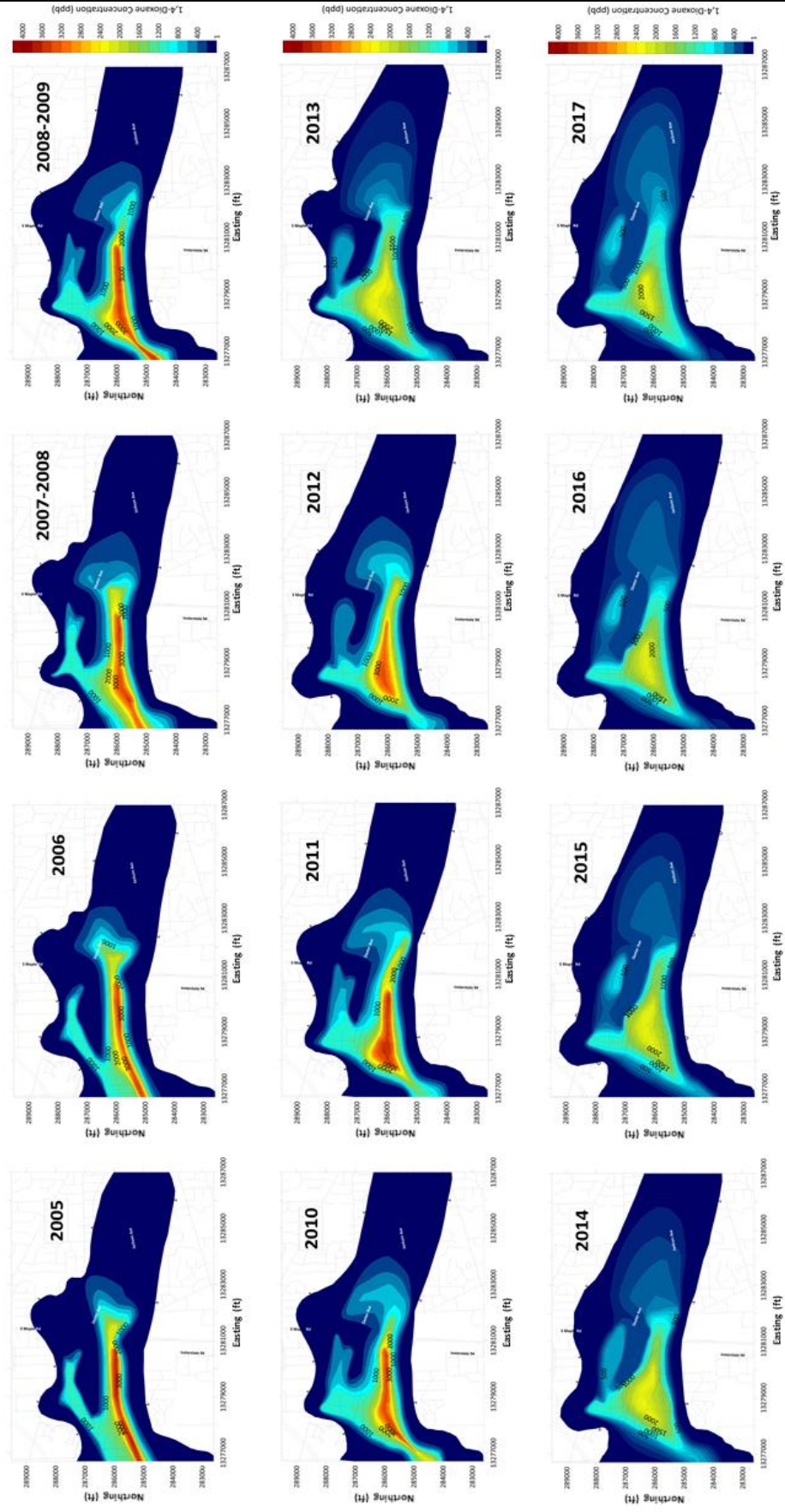


Fig. S5. 1,4-dioxane concentration changes during the entire study period (2005-2017).



Fig. S6. Spatial moment analysis site summary.

<b>MAROS Site Summary</b>						
<b>Project:</b> Gelman Site-Eastern Area			<b>User Name:</b> JACKSON/LEMKE			
<b>Location:</b> Ann Arbor			<b>State:</b> Michigan			
<b>User Defined Site and Data Assumptions</b>						
<b>Hydrogeology and Plume Information:</b>				<b>Downgradient Information:</b>		
Groundwater Seepage Velocity: 1 ft/yr				<b>Distance from Edge of Tail to Nearest:</b>		
Current Plume Length: 12800 ft				Downgradient receptor: 4800 ft		
Current Plume Width: 3200 ft				Downgradient property: 4800 ft		
Number of Tail Wells: 49				<b>Distance from Source to Nearest:</b>		
Number of Source Wells: 3				Downgradient receptor: 17600 ft		
			Downgradient property: 17600 ft			
<b>Contaminants of Concern (COC's)</b>						
1,4-DIOXANE (P-DIOXANE)						
<b>Well Summary</b>						
Well Name	Source / Tail / Delineation		Record Count	Sample Date Range		Priority Constituent
				Minimum	Maximum	
MW-15d	S		64	10/15/1987	7/31/2015	1,4-DIOXANE (P-DIOXANE)
MW-16	T		11	6/10/1994	8/21/2018	1,4-DIOXANE (P-DIOXANE)
MW-17	T		56	6/7/1990	1/25/2018	1,4-DIOXANE (P-DIOXANE)
MW-30d	T		75	2/16/2001	8/28/2018	1,4-DIOXANE (P-DIOXANE)
MW-54d	T		79	8/28/2000	7/20/2018	1,4-DIOXANE (P-DIOXANE)
MW-55	T		29	8/28/2000	6/8/2016	1,4-DIOXANE (P-DIOXANE)
MW-71	T		56	10/17/2001	6/27/2018	1,4-DIOXANE (P-DIOXANE)
MW-72d	T		75	12/6/2001	7/23/2018	1,4-DIOXANE (P-DIOXANE)
MW-72s	T		51	12/24/2002	6/26/2018	1,4-DIOXANE (P-DIOXANE)
MW-76d	T		22	4/8/2002	7/6/2015	1,4-DIOXANE (P-DIOXANE)
MW-76i	T		103	4/8/2002	9/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-76s	T		119	4/8/2002	9/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-77	T		67	4/22/2002	9/24/2018	1,4-DIOXANE (P-DIOXANE)
MW-79s	T		98	7/25/2002	8/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-81	T		87	11/7/2002	8/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-82s	T		46	11/7/2002	9/21/2018	1,4-DIOXANE (P-DIOXANE)

# MAROS Site Summary

Gelman Site-Eastern Area

User Name: JACKSON/LEMKE

Ann Arbor

State: Michigan

MW-83s	T	48	10/16/2002	6/5/2018	1,4-DIOXANE (P-DIOXANE)
MW-84s	T	122	1/6/2003	9/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-85	T	115	3/14/2003	8/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-87d	T	93	7/24/2003	2/2/2017	1,4-DIOXANE (P-DIOXANE)
MW-87s	T	98	9/15/2003	2/2/2017	1,4-DIOXANE (P-DIOXANE)
MW-88	T	93	8/6/2003	8/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-90	T	56	6/19/2003	5/16/2018	1,4-DIOXANE (P-DIOXANE)
MW-91	T	28	7/14/2006	5/22/2018	1,4-DIOXANE (P-DIOXANE)
MW-92	T	47	8/30/2004	5/16/2018	1,4-DIOXANE (P-DIOXANE)
MW-98d	T	35	4/3/2006	6/12/2018	1,4-DIOXANE (P-DIOXANE)
MW-100	T	41	4/4/2006	9/12/2017	1,4-DIOXANE (P-DIOXANE)
MW-101	T	63	4/4/2006	8/16/2018	1,4-DIOXANE (P-DIOXANE)
MW-103d	T	56	4/7/2006	8/9/2018	1,4-DIOXANE (P-DIOXANE)
MW-103s	T	113	4/7/2006	9/6/2018	1,4-DIOXANE (P-DIOXANE)
MW-104	T	35	8/3/2011	8/16/2018	1,4-DIOXANE (P-DIOXANE)
MW-105d	S	33	8/3/2006	8/23/2017	1,4-DIOXANE (P-DIOXANE)
MW-105s	S	50	8/3/2006	8/13/2018	1,4-DIOXANE (P-DIOXANE)
MW-106d	T	12	8/3/2006	1/17/2011	1,4-DIOXANE (P-DIOXANE)
MW-106s	T	51	8/3/2006	8/9/2018	1,4-DIOXANE (P-DIOXANE)
MW-107	T	56	11/9/2006	8/21/2018	1,4-DIOXANE (P-DIOXANE)
MW-108d	T	55	11/9/2006	8/13/2018	1,4-DIOXANE (P-DIOXANE)
MW-108s	T	40	11/9/2006	8/13/2018	1,4-DIOXANE (P-DIOXANE)
MW-110	T	51	2/12/2007	6/8/2018	1,4-DIOXANE (P-DIOXANE)
MW-112d	T	3	10/18/2017	5/1/2018	1,4-DIOXANE (P-DIOXANE)
MW-112i	T	97	5/10/2007	9/5/2018	1,4-DIOXANE (P-DIOXANE)
MW-112s	T	10	11/4/2014	3/7/2016	1,4-DIOXANE (P-DIOXANE)
MW-113	T	45	12/11/2007	8/16/2018	1,4-DIOXANE (P-DIOXANE)
MW-115	T	60	11/30/2007	8/17/2018	1,4-DIOXANE (P-DIOXANE)
MW-116	T	37	11/30/2007	8/17/2018	1,4-DIOXANE (P-DIOXANE)
MW-118	T	45	2/13/2008	8/7/2018	1,4-DIOXANE (P-DIOXANE)
MW-119	T	36	11/12/2008	5/22/2018	1,4-DIOXANE (P-DIOXANE)
MW-121d	T	23	2/14/2013	7/16/2018	1,4-DIOXANE (P-DIOXANE)
MW-122s	T	41	12/16/2008	8/27/2018	1,4-DIOXANE (P-DIOXANE)
MW-129d	T	19	3/11/2015	1/19/2018	1,4-DIOXANE (P-DIOXANE)
MW-130i	T	18	10/22/2014	7/17/2018	1,4-DIOXANE (P-DIOXANE)
MW-133d	T	31	8/18/2011	7/23/2018	1,4-DIOXANE (P-DIOXANE)



Fig S7. Spatial moment analysis summary.

# MAROS Spatial Moment Analysis Summary

Project: Gelman Site-Eastern Area

User Name: JACKSON/LEMKE

Location: Ann Arbor

State: Michigan

Effective Date	<u>0th Moment</u>	<u>1st Moment (Center of Mass)</u>		Source Distance	<u>2nd Moment (Spread)</u>		Number of Wells
	Estimated Mass (Kg)	Xc (ft)	Yc (ft)		Sigma XX (sq ft)	Sigma YY (sq ft)	
<b>1,4-DIOXANE (P-DIOXANE)</b>							
7/1/2006	6.4E+03	13,279,793	285,716	4,374	2,524,844	430,869	36
7/1/2007	8.1E+03	13,279,910	285,789	4,512	2,507,251	519,839	40
7/1/2008	8.7E+03	13,279,829	285,883	4,487	2,597,329	583,372	43
7/1/2009	1.0E+04	13,279,824	285,876	4,479	3,331,904	617,804	40
7/1/2010	1.1E+04	13,279,883	285,910	4,547	3,266,811	633,127	39
7/1/2011	1.2E+04	13,279,757	285,969	4,469	2,571,501	687,680	44
7/1/2012	1.2E+04	13,279,783	286,004	4,509	2,887,706	680,771	41
7/1/2013	1.0E+04	13,280,001	286,139	4,765	2,892,116	687,548	42
7/1/2014	8.5E+03	13,280,131	286,519	5,081	3,175,277	451,615	46
7/1/2015	7.8E+03	13,280,040	286,554	5,027	2,796,952	483,218	50
7/1/2016	7.3E+03	13,280,271	286,413	5,140	3,654,771	486,693	46
7/1/2017	7.4E+03	13,280,358	286,609	5,319	3,581,780	476,993	46

# MAROS Spatial Moment Analysis Summary

Project: Gelman Site-Eastern Area

User Name: JACKSON/LEMKE

Location: Ann Arbor

State: Michigan

## Spatial Moment Analysis Summary:

Moment Type	Constituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
0th Moment	1,4-DIOXANE (P-DIOXANE)	0.20	-6	63.1%	S
First Moment	1,4-DIOXANE (P-DIOXANE)	0.07	46	100.0%	I
Second Moment X	1,4-DIOXANE (P-DIOXANE)	0.14	32	98.4%	I
Second Moment Y	1,4-DIOXANE (P-DIOXANE)	0.17	2	52.7%	NT

Note: The following assumptions were applied for the calculation of the Zeroth Moment:

**Porosity:** 0.30

**Saturated Thickness:** Uniform: 130 ft

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); (ND) Non Detect.

Note: The Sigma XX and Sigma YY components are estimated using the given field coordinate system and then rotated to align with the estimated groundwater flow direction. Moments are not calculated for sample events with less than 6 wells.

Fig. S8. Zeroth moment analysis results.

# MAROS Zeroth Moment Analysis

Project: Gelman Site-Eastern Area

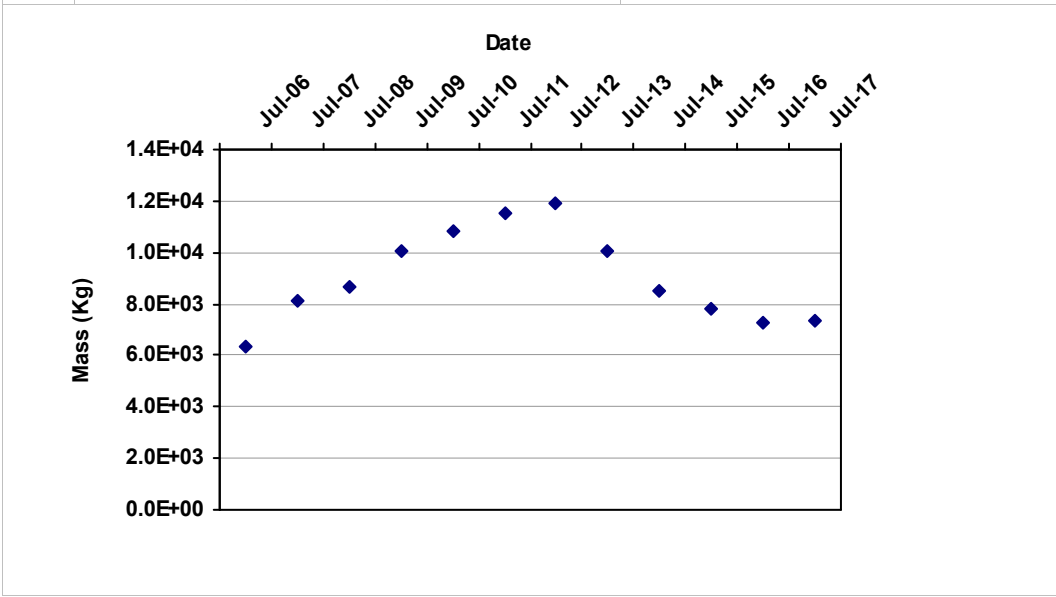
User Name: JACKSON/LEMKE

Location: Ann Arbor

State: Michigan

## Change in Dissolved Mass Over Time

COC: 1,4-DIOXANE (P-DIOXANE)



**Porosity:** 0.30

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**Saturated Thickness:**  
Uniform: 130 ft

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**Mann-Kendall S Statistic:**  
-6

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**Confidence in Trend:**  
63.1%

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**Coefficient of Variation:**  
0.20

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**Zeroth Moment Trend:**  
S

## Data Table:

Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
7/1/2006	1,4-DIOXANE (P-DIOXANE)	6.4E+03	36
7/1/2007	1,4-DIOXANE (P-DIOXANE)	8.1E+03	40
7/1/2008	1,4-DIOXANE (P-DIOXANE)	8.7E+03	43
7/1/2009	1,4-DIOXANE (P-DIOXANE)	1.0E+04	40
7/1/2010	1,4-DIOXANE (P-DIOXANE)	1.1E+04	39
7/1/2011	1,4-DIOXANE (P-DIOXANE)	1.2E+04	44
7/1/2012	1,4-DIOXANE (P-DIOXANE)	1.2E+04	41
7/1/2013	1,4-DIOXANE (P-DIOXANE)	1.0E+04	42
7/1/2014	1,4-DIOXANE (P-DIOXANE)	8.5E+03	46
7/1/2015	1,4-DIOXANE (P-DIOXANE)	7.8E+03	50
7/1/2016	1,4-DIOXANE (P-DIOXANE)	7.3E+03	46
7/1/2017	1,4-DIOXANE (P-DIOXANE)	7.4E+03	46

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); ND = Non-detect. Moments are not calculated for sample events with less than 6 wells.

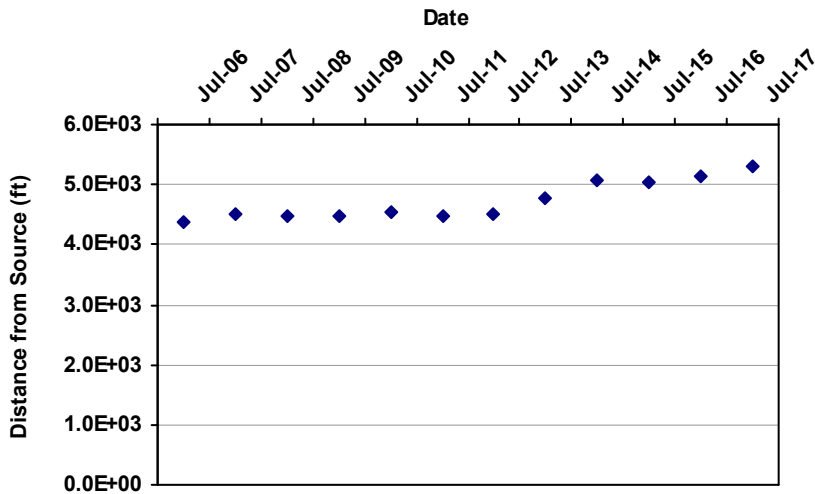
Fig. S9. First moment analysis results - distance from source to center of mass.

# MAROS First Moment Analysis

<b>Project:</b> Gelman Site-Eastern Area <b>Location:</b> Ann Arbor	<b>User Name:</b> JACKSON/LEMKE <b>State:</b> Michigan
------------------------------------------------------------------------	-----------------------------------------------------------

**COC:** 1,4-DIOXANE (P-DIOXANE)

**Distance from Source to Center of Mass**



**Mann-Kendall S Statistic:**

46

**Confidence in Trend:**

100.0%

**Coefficient of Variation:**

0.07

**First Moment Trend:**

I

**DATA TABLE**

Effective Date	Constituent	Xc (ft)	Yc (ft)	Distance from Source	Number of Wells
7/1/2006	1,4-DIOXANE (P-DIOXANE)	13,279,793	285,716	4,374	36
7/1/2007	1,4-DIOXANE (P-DIOXANE)	13,279,910	285,789	4,512	40
7/1/2008	1,4-DIOXANE (P-DIOXANE)	13,279,829	285,883	4,487	43
7/1/2009	1,4-DIOXANE (P-DIOXANE)	13,279,824	285,876	4,479	40
7/1/2010	1,4-DIOXANE (P-DIOXANE)	13,279,883	285,910	4,547	39
7/1/2011	1,4-DIOXANE (P-DIOXANE)	13,279,757	285,969	4,469	44
7/1/2012	1,4-DIOXANE (P-DIOXANE)	13,279,783	286,004	4,509	41
7/1/2013	1,4-DIOXANE (P-DIOXANE)	13,280,001	286,139	4,765	42
7/1/2014	1,4-DIOXANE (P-DIOXANE)	13,280,131	286,519	5,081	46
7/1/2015	1,4-DIOXANE (P-DIOXANE)	13,280,040	286,554	5,027	50
7/1/2016	1,4-DIOXANE (P-DIOXANE)	13,280,271	286,413	5,140	46
7/1/2017	1,4-DIOXANE (P-DIOXANE)	13,280,358	286,609	5,319	46

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events). Moments are not calculated for sample events with less than 6 wells.

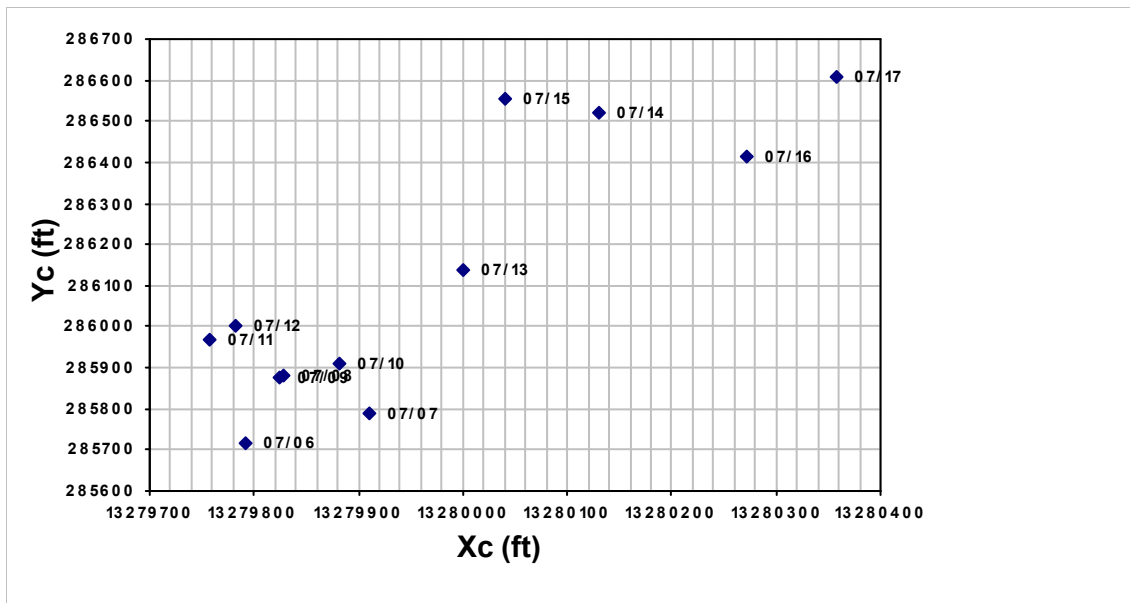
Fig. S10. First moment analysis results - change in location of center of mass over time.

# MAROS First Moment Analysis

Project: Gelman Site-Eastern Area      User Name: JACKSON/LEMKE  
 Location: Ann Arbor      State: Michigan

COC: 1,4-DIOXANE (P-DIOXANE)

## Change in Location of Center of Mass Over Time



**Groundwater Flow Direction:**



**Source Coordinates**

X: 13,275,936

Y: 283,652

Effective Date	Constituent	Xc (ft)	Yc (ft)	Distance from Source (ft)	Number of Wells
7/1/2006	1,4-DIOXANE (P-D)	13,279,793	285,716	4,374	36
7/1/2007	1,4-DIOXANE (P-D)	13,279,910	285,789	4,512	40
7/1/2008	1,4-DIOXANE (P-D)	13,279,829	285,883	4,487	43
7/1/2009	1,4-DIOXANE (P-D)	13,279,824	285,876	4,479	40
7/1/2010	1,4-DIOXANE (P-D)	13,279,883	285,910	4,547	39
7/1/2011	1,4-DIOXANE (P-D)	13,279,757	285,969	4,469	44
7/1/2012	1,4-DIOXANE (P-D)	13,279,783	286,004	4,509	41
7/1/2013	1,4-DIOXANE (P-D)	13,280,001	286,139	4,765	42
7/1/2014	1,4-DIOXANE (P-D)	13,280,131	286,519	5,081	46
7/1/2015	1,4-DIOXANE (P-D)	13,280,040	286,554	5,027	50
7/1/2016	1,4-DIOXANE (P-D)	13,280,271	286,413	5,140	46
7/1/2017	1,4-DIOXANE (P-D)	13,280,358	286,609	5,319	46

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events). Moments are not calculated for sample events with less than 6 wells.