ANAEROBIC BIODEGRADATION RATES OF ORGANIC CHEMICALS IN GROUNDWATER: A SUMMARY OF FIELD AND LABORATORY STUDIES

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1.0 INTRODUCTION

Solid and hazardous wastes may pose a considerable threat to the health of humans and the environment. Under the Resource Conservation and Recovery Act (RCRA) of 1976 the U.S. EPA is appointed the task of managing these risks through the development and implementation of regulations. To this end, the EPA develops and uses fate and transport mathematical/computer models to aid in the assessment of risk from waste management practices. The input parameters of these models may be used to describe, in mathematical terms, the physical and chemical properties of actual landfill sites. These models may be used to develop a probability distribution of concentrations by performing a myriad of simulations, each time selecting sites parameters from a nation-wide database. This technique is known as Monte Carlo analysis and has proven a useful tool in risk analysis.

The EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP: U.S. EPA, 1996) is the subsurface fate and transport model which EPA's Office of Solid Waste implements on a nationwide basis using Monte Carlo analysis techniques. The implementation procedure requires nationally representative distributions of first order biodegradation rates.

EPA uses anaerobic biodegradation rates in the subsurface fate and transport model. The Agency considers that although anaerobic biodegradation is not the slowest activity, it is less likely that data collected under anaerobic conditions would lead to an overestimation of the degradation rate. In general, the concentrations of oxygen and nitrate are insignificant in ground waters that have been impacted with leachate from landfills. This condition results from prior microbial consumption of oxygen or nitrate that was supported by the electron acceptor demand of materials in the landfill leachate. Consequently, the rate of supply of oxygen and nitrate into impacted ground waters is slow. The rate of supply is limited by mass transfer processes from ground water that has not been impacted (and as a consequence has oxygen and nitrate available) into the plume impacted with leachate from a landfill. As a result, the only microbial processes that are generally available for biodegradation of hazardous organic compounds in ground water impacted with leachate from landfills are the processes of iron reduction, sulfate reduction, and methanogenesis (Krumholz et al, 1996). Therefore, EPA considers selected rate constants provided by laboratory and field studies that were conducted under the iron reducing, sulfate reducing, or methanogenic conditions to be the rate constants that are appropriate for use in EPACMTP. EPA does not consider rate constants provided by laboratory and field studies that were conducted under aerobic or nitrate reducing conditions to be appropriate for use in EPACMTP.

EPA developed a protocol to generate national distributions of anaerobic biodegradation rates for organic chemicals for use in the model (53 FR 22300, June 15, 1988). The protocol requires collecting samples from six sites: three sites in the northern half of the United States; and three sites located in the southern half of the country. Ideally, these six sites will represent the various pH and redox environments prevalent in the country. However, the protocol has not been implemented widely by the industry so far. Meanwhile, many laboratory and field studies on the anaerobic biodegradation of chemicals have become available since the protocol was developed more than ten years ago. Suggestions were made to critically evaluate these studies and incorporate the results in modeling. Therefore, EPA convened a workshop in Atlanta, Georgia, on anaerobic biodegradation of organic chemicals in 1997. Representatives from academia, industry and the EPA participated in discussions. Written comments from an environmental group were also considered at the workshop. Based on these discussions and other inputs from EPA scientists, the Agency developed criteria for the evaluation of the field as well as laboratory studies. The criteria are listed in Appendices A and B (laboratory and field studies, respectively).

At the workshop, industry representatives provided a report summarizing field and laboratory studies on anaerobic biodegradation of organic compounds. The report entitled “Anaerobic Biodegradation of Organic Chemicals in Groundwater: A Summary of Field and Laboratory Studies” was prepared for the American Petroleum Institute (API) and others by the Syracuse Research Center, 1997. All the research articles reviewed in the report were also submitted to EPA by the API. The criteria used by Syracuse Research Corporation are presented in Appendix C. Since the criteria used by Syracuse Research Center (Appendix C) to review research papers was less stringent than the criteria decided upon at the workshop, EPA conducted a second review of the API-submitted Syracuse Research Center Report. In addition, EPA conducted a literature review to collect additional studies on biodegradation of various organic chemicals (both laboratory as well as field). For purposes of this report, biodegradation is defined as “removal of a compound from ground water through biological activity”. Only studies which were conducted with aquifer materials under anaerobic conditions were selected for review. In addition studies carried out on mixtures of compounds, and studies where the aquifer material was seeded with microorganisms from other sources were not included. The studies were then evaluated to see if they satisfied the proposed EPA criteria. Biodegradation rates from studies which met the proposed criteria were used to develop a distribution of first order rates to be used as potential input to the EPA’s subsurface fate and transport model.

2.0 REVIEW OF BIODEGRADATION STUDIES

The studies submitted by Syracuse Research Center were divided into field and laboratory studies and the results from these studies are summarized separately. Results of a study were rejected if the study did not satisfy the criteria indicated as unacceptable in Appendix A or B. Appendices D, E, F, and G summarize the review of available biodegradation studies satisfying the proposed EPA criteria (Appendices A & B). The laboratory studies are summarized in Appendix D and the field studies are summarized in Appendix E. Appendix F has tables summarizing both field and laboratory studies for each compound. The references for each compound are listed in Appendix G. A summary of the distribution of rates for each compound is provided in Table 2.1.

Results of both field and laboratory studies are considered for the development of biodegradation rates for use in the model. Each category (field or laboratory) is further subdivided based on the temperature, pH and the redox regime. The biodegradation rate of a chemical depends, among other factors, on both the temperature and pH of the subsurface environment at the site. The subsurface reducing environment was assumed to be grouped into two broad categories: methanogenic; and sulfate reducing. Studies which identified iron reducing conditions were grouped under sulfate reducing. Studies which were purely denitrifying were not included as denitrification is believed to occur predominantly in the vadose zone (Krumholz et al, 1996) . If a study met all criteria but was missing either temperature or pH or both, then pH and temperature were assigned to the study as follows:

1) pH: assume neutral range (6-8), for both laboratory and field; and

2) Temperature: assume 25 ^{o}C for laboratory, and for field studies refer to the nationwide distribution of temperature shown in Figure 2.1.

The pH regimes were grouped as: acidic (< 6), neutral (6-8), and alkaline (> 8). Two distinct temperature ranges were considered (# 15 ^{o}C and > 15 ^{o}C). Each table includes the lag time for degradation where reported and any special observations regarding the study. If a multiple redox regime was reported in the study (*e.g.*, SO_4/CH_4/NO_3), the study was classified under the first relevant redox regime reported, in this case sulfate reducing. If no redox regime was reported the study was classified as sulfate reducing. If multiple studies were conducted at a site, a simple average was computed for the biodegradation rate and the average was used. The average was computed so that one site may not unduly bias the distribution of rate constants. The individual rates are also reported in parentheses following the average.

Information from the tables in Appendix F for each compound is used in the subsurface Monte-Carlo fate and transport modeling. In a Monte-Carlo realization, a site is selected along with the subsurface temperature and the pH. The reducing environment is randomly chosen, each environment having an equal likelihood of being selected. Then an anaerobic biodegradation rate is picked from the appropriate cell of the table corresponding to the selected reducing environment (the rates listed within a cell all have an equal likelihood of being chosen). The rate is then used for that site in the analysis. For the next Monte Carlo site realization, the model then selects a rate from the table based on the temperature, pH, and either methanogenic or sulfate reducing environment at random with replacement. The process is repeated for the total number of Monte Carlo realizations.

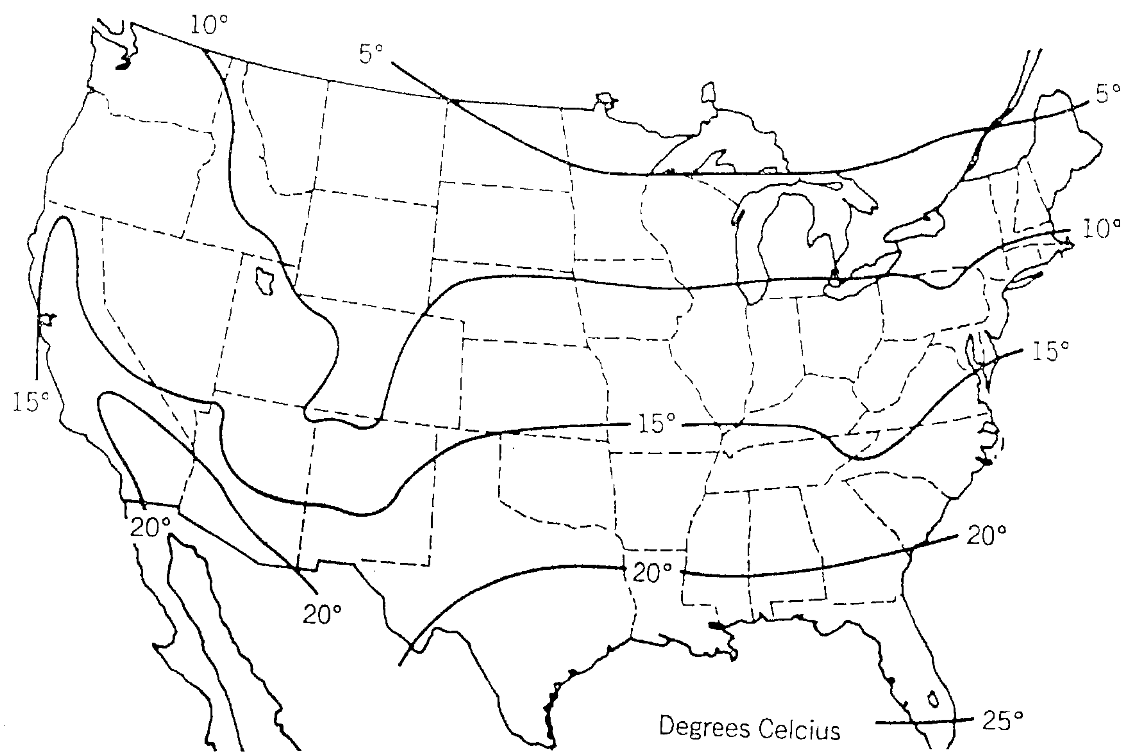

Figure 2.1 Temperature of Groundwater in the United States at Depths of 10-20 meters (Collins, 1925)

Table 2.1
Summary of Rate Constants

CAS Number / Chemical Name	Rate Constant (1/day)							
	Most Likely Estimate	Min	Max	Median	Standard Deviation	Distribution Type	Molar Yield	Reaction Product
000071-43-2 / Benzene	0	0	0.071	0	0.0152	--	--	Not Identified
000108-88-3 / Toluene	0.02	0	0.186	0.02	0.0372	--	--	Not Identified
000100-41-4 / Ethylbenzene	0.0031	0	0.46	0.0031	0.0762	--	--	Not Identified
000108-38-3 / m-Xylene	0.006	0	0.32	0.006	0.0675	--	--	Not Identified
000095-47-6 / o-Xylene	0.004	0	0.21	0.004	0.0468	--	--	Not Identified
000106-42-3 / p-Xylene	0.0052	0	0.17	0.0052	0.0367	--	--	Not Identified
000056-23-5 / Carbon Tetrachloride	0.16343	0	1.73	0.16343	0.572	--	--	Not Identified
000067-66-3 / Chloroform	0.0315	0.004	0.25	0.0315	0.0884	--	--	Not Identified
000107-06-2 / 1,2-Dichloroethane	0.0076	0.0076	0.0076	0.0076	N.A.	--	--	Not Identified
000075-09-2 / Dichloromethane	0.0064	0.0064	0.0064	0.0064	N.A.	--	--	Not Identified
000079-34-5 / 1,1,2,2-Tetrachloroethane	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000127-18-4 / Tetrachloroethylene	0.00186	0	0.071	0.00186	0.0223	--	--	Trichloroethylene
000071-55-6 / 1,1,1-Trichloroethane	0.00355	0	0.041	0.00355	0.0130			Not Identified
000079-00-5 / 1,1,2-Trichloroethane	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000079-01-6 / Trichloroethylene	0.0016	0.00082	0.04	0.0016	0.00889	--	--	Not Identified
000075-01-4 / Vinyl Chloride	0.00405	0	0.0582	0.00405	0.0139	--	--	Not Identified

Table 2.1 (continued)
Summary of Rate Constants

CAS Number / Chemical Name	Rate Constant (1/day) Most Likely Estimate	Min	Max	Median	Standard Deviation	Distribution Type	Molar Yield	Reaction Product
000108-95-2 / Phenol	0.032	0	0.2	0.032	0.0651	--	--	Not Identified
000095-48-7 / o-Cresol	0.005	0	0.034	0.005	0.0172	--	--	Not Identified
000108-39-4 / m-Cresol	0.029	0.0029	0.033	0.029	0.0138	--	--	Not Identified
000106-44-5 / p-Cresol	0.037	0.035	0.048	0.037	0.007	--	--	Not Identified
000120-83-2 / 2,4-Dichlorophenol	0.016	0	0.12	0.016	0.0501	--	--	Not Identified
000088-06-2 / 2,4,6-Trichlorophenol	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000087-86-5 / Pentachlorophenol	0	0	0	0	0	--	--	Not Identified
000075-69-4 / Trichloroflouromethane (CFC-11)	0.0016	0.0016	0.0016	0.0016	N.A.	--	--	Not Identified
000075-71-8 / Dichlorodifluoromethane (CFC-12)	0	0	0	0	N.A.	--	--	Not Identified
000076-13-1 / 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC 113)	0	0	0	0	N.A.	--	--	Not Identified
000067-64-1 / Acetone	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000078-93-3 / Methyl Ethyl Ketone	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000108-10-1 / Methyl Isobutyl Ketone	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000064-19-7 / Aceic Acid	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000103-32-2 / Phenylacetic Acid	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000083-32-9 / Acenaphthalene	0.0043	0.0043	0.0043	0.0043	N.A.	--	--	Not Identified
000086-73-7 / Fluorene	0.00015	0	0.00145	0.00015	0.00069	--	--	Not Identified

Table 2.1 (continued)
Summary of Rate Constants

CAS Number / Chemical Name	Rate Constant (1/day) Most Likely Estimate	Min	Max	Median	Standard Deviation	Distribution Type	Molar Yield	Reaction Product
000090-12-0 / 1-Methylnaphthalene	0	0	0.057	0	0.0214	--	--	Not Identified
000091-20-3 / Naphthalene	0	0	0.03	0	0.00791	--	--	Not Identified
000085-01-8 / Phenanthrene	N.A.	N.A.	N.A.	N.A.	N.A.	--	--	Not Identified
000092-52-4 / 1,1'-Biphenyl	0.00016	0	0.019	0.00016	0.00944	--	--	Not Identified
000098-82-8 / Cumene	0	0	0	0	N.A.	--	--	Not Identified
000123-91-1 / Dioxane	0	0	0	0	N.A.	--	--	Not Identified
000067-56-1 / Methanol	0.036	0	0.34	0.036	0.0697	--	--	Not Identified
000098-95-3 / NitroBenzene	0.0037	0.0037	0.1168	0.0037	0.0427	--	--	Not Identified
000110-86-1 / Pyridine	0.01	0	0.02	0.01	0.0102	--	--	Not Identified
000100-42-5 / Styrene	0	0	0	0	N.A.	--	--	Not Identified
000108-67-8 / 1,3,5-Trimethylbenzene	0	0	0.0039	0	0.00174	--	--	Not Identified

Notes:
- An N.A. in all columns for a compound indicates no study met the proposed criteria.
- An N.A. in the standard deviation column for a compound indicates that there was only one study that met the proposed criteria and so it is not possible to calculate a standard deviation.

3.0 REFERENCES

Collins , W.D., Temperature of water available for individual use in the United States: U.S. Geol. Surv. Water Supply Papers 520-F, p97-104, 1925.

Krumholz, L.R., Caldwell, M.E., and Suflita, J.M., Biodegradation of 'BTEX' hydrocarbons under anaerobic conditions, pages 61 through 99 in Bioremediation: Principles and Applications, R.L. Crawford and D.L. Crawford, Cambridge University Press, 1996.

Syracuse Research Center. Anaerobic Biodegradation of Organic Chemicals in Groundwater: A Summary of Field and Laboratory Studies, SRC TR-97-0223F, 1997.

U.S. EPA, EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP): Background Document, Office of Solid Waste, Washington, D.C., 20460, 1996.

APPENDIX A
CRITERIA FOR EVALUATING BIODEGRADATION RATE (LABORATORY STUDIES)

Italicized criteria are common with Syracuse Research Corporation's criteria.

A.1 LABORATORY MICROCOSMS

1. **The experiment should have been conducted with aquifer materials and aquifer bacteria*.

2. **A proper control study should have been conducted to separate abiotic losses from biotransformation*.

3. * Scaling factors for normalizing reaction rate (e.g. dry cell mass) should not have been used. If a scaling factor was used, it should be reported so that it is possible to calculate a first order rate.

4. * *Concentration decrease with time should be documented in the study*.

5. Experimental Conditions

   - * No artificial growth media should be used in the microcosm study.
   - * *The experiment should be carried out under anaerobic conditions*.
   - * In case of a volatile contaminants, there should be no head space in the flask in which the study is carried out.
   - The incubation should be carried out under conditions that closely replicate the subsurface environment in terms of temperature, pH, and light conditions. The incubation should be carried out in the dark.

6. The experiment should have good mass balance. That is, the loss of parent organic carbon should be accounted for by the intermediates and products. Are other products generated in stoichiometric proportions?

7. If the target compounds were administered to the microcosm using a carrier solvent, how was this accomplished? If a carrier solvent was used, this could potentially alter the consumption of electron donors and acceptors. Was a control done to account for the effect of the carrier solvent?

8. The soil/water ratio in the microcosms and the rate constants derived from the data should accurately reflect the in situ soil/water ratio.

9. Time dependency of rate data. Criteria for statistical analysis of data (e.g., questions regarding the degree of replication or standard error).

(To fit a first order model ideally there should be a concentration decrease of at least two orders of magnitude. However, it is recognized that in most cases it is possible to get only an order of magnitude decrease.)

A.2 BATCH AND COLUMN STUDIES:

1. The column should be packed and operated under anaerobic conditions. The column must be large enough to prevent wall effects (i.e. column diameter 20 times the grain diameter).

2. The chemistry of the water passed through the column (or batch reactor) must be similar to the composition of the groundwater at the site.

3. * A tracer study must be conducted to characterize the hydraulic properties of the column (e.g., mean fluid residence time and hydrodynamic dispersion).

4. The flow velocity through the column/batch reactor should mimic the groundwater flow velocity at the site.

5. The feed reservoirs, feed lines, and effluent lines need to be periodically sterilized to prevent/minimize microbial contamination of the column.

6. The column needs to be operated long enough to obtain stable effluent concentrations in order to establish proper breakthrough and steady-state reaction processes.

7. In order to accurately assess the biodegradation rate within the column, samples along the column length (using multiple side ports) must be collected to determine the concentration profile(s) within the column (i.e., concentration versus length).

These criteria are in addition to the criteria for evaluating laboratory microcosm studies.
*Criteria for acceptance/rejection of study.

APPENDIX B
CRITERIA FOR EVALUATING BIODEGRADATION RATE (FIELD STUDIES)

1. * *The study should be conducted in the anaerobic portion of the plume.*

2. * *A tracer study should be carried out that can be used to estimate the processes of dilution, sorption, or volatilization that can contribute to attenuation of contaminants.*

3. * If a transport model was employed to estimate a biodegradation rate, reasonable parameter values should be used to describe dispersion and sorption processes. The model used should be appropriate to the hydrogeologic setting and should have been verified.

4. **Data on concentration decrease with time should be reported in the study.*

5. No scaling factor should be used to normalize the data. If a factor is used the study must document the factor so that a first order rate can be calculated.

6. Time dependency of rate data. Criteria for statistical analysis of data (e.g., questions regarding the degree of replication or standard error).

(To fit a first order model ideally there should be a concentration decrease of at least two orders of magnitude. However, it is recognized that in most cases it is possible to get only an order of magnitude decrease.)

APPENDIX C
CRITERIA FOR EVALUATING BIODEGRADATION RATE STUDIES
(Syracuse Research Center)

LABORATORY MICROCOSMS

1. Study Conducted Under Anaerobic Conditions

2. Experiment Conducted With Grab Samples of Aquifer Material or Ground Water

3. Study Has Controls to Determine Abiotic Losses

4. Need Data on Concentration Decrease With Time

FIELD STUDIES

1. Studies of Anaerobic Portion of Aquifer System

2. Suitable Conservative Tracer Other Than Target Compound Available to Correct for Dilution, Sorption, Advection and Dispersion Processes

3. Need Data on Concentration Decrease With Time/Distance (Need flow velocity to correlate distance with time)

APPENDIX D
LABORATORY STUDIES FOR ALL COMPOUNDS

Table D.1
Summary Table for Anaerobic Biodegradation Rate Constants for Benzene According to EPA Protocol
(Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0	20	0[1]	15	[1] No Redox Regime Given
	6-8	0.0015[2]	9			[2] Meth/Fe/Mn
		0[3]	2	0.047*	11	[3] Meth/SO_4
						*8 days lag
		0.052*	11			* 21 days lag
		0.071[14]	27	0 [11]	3	[14] Meth/Fe
						[11] No Redox Regime Given
		0	19	0.0029 [10]	17	[10] No Redox Regime Given
		0.0 [6] (0; 0)	1	0.0065 [13]	28	[6] 1 site 2 studies of Meth/SO_4 and Meth/NO_3
						[13] Fe
		0 [7]	18	0 [12]	2	[7] Meth/Fe/NO_3
		0.031	3			[12] Fe
	> 8	No Studies		No Studies		

Table D.1 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Benzene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
> 15	< 6	No Studies		No Studies		
	6-8	0	7	0.0041 [8]	6	[8] SO_4/Fe; 121 days lag
		0	14	0.003	8	
				0.0237 [15]	6	[15] SO_4/Fe; 184 days lag
		0	8	0	4	
		0.0074	26			*140 days lag
		0.0 [17] (0; 0)	13			[17] Meth/SO_4
	> 8	No Studies		No Studies		

Table D.2
Summary Table for Anaerobic Biodegradation Rate Constants for Toluene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0.043[12]	27	0.016 [13]	10	[12] Meth/Fe
						[13] No Redox Regime Given
		0.093[14]	8	0.087 [15]	14	[14] Meth/Fe/Mn
						[15] Fe
		0 [16]	19	0.0045 [17]	17	[16] Meth/Fe/NO_3
						[17] No Redox Regime Given
		0 [21] (0 [22]; 0)	1	0.010 [20]	28	[21] 1 site; 2 studies one with [22] Meth/NO_3
						[20] Fe
		0.10 [24]	2			[24] Meth/Fe/Mn
	> 8	No Studies		No Studies		

Table D.2 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Toluene According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
> 15	< 6	No Studies		No Studies		
	6-8	0	7	0.11	3	
		0.034 [25] (0.036*[1]; 0; 0.032*[2]; 0.06*[3]; 0.012; 0.063)	11	0.0446 [26]	9	[25] 1 site; 6 studies;*[1]208 days lag; *[2] 99 days lag *[3]302 days lag [26] SO_4/Fe
		0.028 [28] (0.036; 0.020)	5	0.011	22	[28] 1 site; 2 studies
		0.0098	4			[29] No Redox Regime Given
		0	12			
		0.018	28			
		0	14			
	> 8	No Studies		No Studies		

Table D.3
Summary Table for Anaerobic Biodegradation Rate Constants for Ethylbenzene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0 [9]	2	0	2	[9] Meth/SO_4
	6-8	0.0055[10]	7	0[11]	9	[10] Meth/Fe/Mn
		0[12] (0 [12a]; 0[12b])	1			[11] No Redox Regime Given [12] 1 site 2 studies; [12a] Meth; [12b] Meth/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0	10	0.0019[14]	8	[14] SO_4/Fe
		0.0029	5			
		0.0076*	16			*140 days lag
		0.29[15] (0.12; 0.46)	6			[15] 1 site; 2 studies
	> 8	No Studies		No Studies		

Table D.4
Summary Table for Anaerobic Biodegradation Rate Constants for m-Xylene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0 [10]	2	0 [11]	2	[10] Meth/SO_4 [11] Fe
	6-8	0	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0	7	0.0204[12]	6	[12] SO_4/Fe
		0.0006	5	0.17*	3	*17 days lag
	> 8	No Studies		No Studies		

Table D.5
Summary Table for Anaerobic Biodegradation Rate Constants for o-Xylene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		0[7]	2	[7] - Fe reducing
	6-8	0	1	0[6]	4	[6] - No redox regime given
		0.071 [8]	19			[8] - Meth/Fe
		0.0091 [9]	8			[9] -Meth/Fe/Mn
		0 [10]	13			[10] -Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0006	6	0	3	
		0	10	0.00559*[11]	5	*[11] - SO_4/Fe; 37 days lag
		0.0087*	18			* - 140 days lag
	> 8	No Studies		No Studies		

Table D.6
Summary Table for Anaerobic Biodegradation Rate Constants for p-Xylene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0[7]	1	0[9]	1	[7]- Meth/SO_4
						[9] - Fe
	6-8	0.057[8]	12	No Studies		[8]- Meth/Fe
		0.0006	3			
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0.17*	2	* - 21 days lag
	> 8	No Studies		No Studies		

Table D.7
Summary Table for Anaerobic Biodegradation Rate Constants for Carbon Tetrachloride According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.23	2	0 [3]	2	[3] Fe/NO_3/Mn
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.8
Summary Table for Anaerobic Biodegradation Rate Constants for Chloroform According to EPA Protocol
(Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.01562 [2] (0.025 *[a]; 0.02 *[a]; 0.025 *[a]; 0.004*[b]; 0.0041*[b])	2	[2] 1 site; 5 studies with No Redox Regime Given *[a] 56 days lag *[b] 112 days lag
	6-8	No Studies		0.142 [3] (0.099; 0.25*; 0.033; 0.099; .25*; .12)	2	[3] 1 site; 6 studies with No Redox Regime Given *14 days lag
	> 8	No Studies		No Studies		

Table D.9
Summary Table for Anaerobic Biodegradation Rate Constants for 1,2-Dichloroethane According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.10
Summary Table for Anaerobic Biodegradation Rate Constants for Dichloromethane According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.11
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 1, 2, 2, -Tetrachloroethane According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.12
Summary Table for Anaerobic Biodegradation Rate Constants for Tetrachloroethylene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.071[6]	2	No Studies		[6] Meth/SO_4
		0 [7]	3			[7] Meth/Fe/NO_3/Mn
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.00073	2	
	6-8	0.0084	2	0.054[8]	6	[8] No Redox Regime Given
				0.0065[9] (0; 0.013)	9	[9] 1 site; 2 studies No Redox Regime Given
	> 8	No Studies		No Studies		

Table D.13
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,1-Trichloroethane According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0.0037	4	0 [6]	4	[6] Fe/NO_3/Mn
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0092 [7] (0.015; 0.0034)	1	0.0092[8] (0.015; 0.0034)	1	[7] 1 site; 2 studies [8] 1 site; 2 studies
				0.0099 [9]	6	[9] No Redox Regime Given
	> 8	No Studies		No Studies		

Table D.14
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 1, 2-Trichloroethane According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.15
Summary Table for Anaerobic Biodegradation Rate Constants for Trichloroethylene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0 [14]	8	0.010 [15]	19	[14] Meth/Fe/NO_3 /Mn
						[15] Fe
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0[16] (0; 0; 0; 0)	10	[16] 1 site; 4 studies with No Redox Regime Given
				0.0011 [17]	18	[17] SO_4/Fe
	6-8	0.016[19] (0.011-0.021)	1	0.0015[18] (0.0017; 0; 0.0029)	18	[18] 1 site; 3 studies with SO_4/Fe
						[19] Meth/Fe/SO_4
		0.039[20] (0.038*[1]; 0.040*[2])	7	0.0090 [21] (0.0077; 0.0082-0.011)	1	[20] 1 site; 2 studies;*[1] 110 days lag; *[2] 108 days lag
						[21] 1 site; 2 studies with No Redox Regime Given
		0.013* (0.0020-0.024)	17	0.0029[22] (0.00057-0.005)	4	*112 days lag
						[22] SO_4/Fe
				0.010	19	
	> 8	No Studies		No Studies		

Table D.16
Summary Table for Anaerobic Biodegradation Rate Constants for Vinyl Chloride According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0.0069[3] (0.0082; 0.0057)	1	[3] 1 site; 2 studies with No Redox Regime Given
				0.0082[4]	1	[4] - No Redox Regime Given
	> 8	No Studies		No Studies		

Table D.17
Summary Table for Anaerobic Biodegradation Rate Constants for Phenol According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		0.20 [2]	7	[2] - No redox regime given
	6-8	0[3]	6	0[4]	4	[4] - No redox regime given
						[3] - Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	0.13*	3	No Studies		* - 50 days lag
	6-8	0.0695[6] (0.068*, 0.071**)	1, 2	No Studies		[6] 1 site; 2 studies, * - 40 days lag, ** - 30 days lag
		0.10[5]	5			[5] - Meth/SO_4
	> 8	No Studies		No Studies		

Table D.18
Summary Table for Anaerobic Biodegradation Rate Constants for o-Cresol According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0[2]	4	0[3]	3	[2] - Meth/Fe/NO_3
						[3] - No redox regime given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0050	5	No Studies		
		0.033 [4] (0.032*; 0.034*)	2, 1			[4] 1 site; 2 studies * - 100 days lag
	> 8	No Studies		No Studies		

Table D.19
Summary Table for Anaerobic Biodegradation Rate Constants for m-Cresol According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0203[1] (0.0029, 0.029*, 0.029*)	3, 2,1	No Studies		[1] 1 site; 3 studies * - 100 days lag
	> 8	No Studies		No Studies		

Table D.20
Summary Table for Anaerobic Biodegradation Rate Constants for p-Cresol According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.036[1] (0.035*, 0.037*)	1, 2	No Studies		[1] 1 site; 2 studies * - 100 days lag
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.21
Summary Table for Anaerobic Biodegradation Rate Constants for 2,4-Dichlorophenol According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.015	2	No Studies		
	6-8	0.017	2	0[3]		[3] -Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.090	5	0.0055	1	
		0.12[4]	3	0	5	[4] - Meth/SO_4
		0.12	1			[2] No Redox Regime Given
	> 8	No Studies		No Studies		

Table D.22
Summary Table for Anaerobic Biodegradation Rate Constants for 2,4,6-Trichlorophenol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.23
Summary Table for Anaerobic Biodegradation Rate Constants for Pentachlorophenol According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	1.98e-03 [1] (1.61e-03-2.36e-03)	1	No Studies		[1] - 1 site 2 studies
		1.414e-03[1] (1.01e-03-2.17e-03; 6.86e-04-1.79e-03)	1			
	6-8	1.97e-03 [3] (1.60e-03-2.42e-03; 1.06e-03-2.80e-03)	1	No Studies		[3] - 1 site 2 studies
	> 8	No Studies		No Studies		

Table D.23 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Pentachlorophenol According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
> 15	< 6	4.94e-03 (7.38e-03 - 2.50e-03)	1	0 [2]	3	[2] No Redox Regime Given
	6-8	0(0; 0)	4	No Studies		[4] - 1 site 2 studies
		5.09e-03[5] (2.91e-03-7.27e-03)	1			[5] - 1 site 2 studies
		5.75e-03[4] (1.63e-03-2.15e-03; 0.0162-3.0e-03)	1			
	> 8	No Studies		No Studies		

Table D.24
Summary Table for Anaerobic Biodegradation Rate Constants for Trichlorofluoromethane According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.25
Summary Table for Anaerobic Biodegradation Rate Constants for Dichlorodifluoromethane According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.26
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,2-Trichloro-1,2,2-trifluoroethane According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.27
Summary Table for Anaerobic Biodegradation Rate Constants for Acetone According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.28
Summary Table for Anaerobic Biodegradation Rate Constants for Methyl Ethyl Ketone According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.29
Summary Table for Anaerobic Biodegradation Rate Constants for Methyl Isobutyl Ketone According to EPA Protocol
(Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.30
Summary Table for Anaerobic Biodegradation Rate Constants for Acetic Acid According to EPA Protocol
(Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.31
Summary Table for Anaerobic Biodegradation Rate Constants for Phenylacetic Acid According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.32
Summary Table for Anaerobic Biodegradation Rate Constants for Acenaphthene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.33
Summary Table for Anaerobic Biodegradation Rate Constants for Fluorene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0	2	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0[3]	3	No Studies		[3] - Meth/NO_3/SO_4
	> 8	No Studies		No Studies		

Table D.34
Summary Table for Anaerobic Biodegradation Rate Constants for 1 - Methylnaphthalene According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0 [4]	1	0[5]	1	[4] Meth/SO_4
						[5] Fe
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.35
Summary Table for Anaerobic Biodegradation Rate Constants for Naphthalene According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0 [9]	2	0 [10]	2	[9] Meth/SO_4 [10] Fe
	6-8	0 [11]	10	0 [12]	1	[11] Meth/Fe/NO_3 [12] No Redox Regime Given
		0 [13]	3	0 [14]	6	[13] Meth/Fe/Mn [14] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0	9	0	8	
	> 8	No Studies		No Studies		

Table D.36
Summary Table for Anaerobic Biodegradation Rate Constants for Phenanthrene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.37
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1'Biphenyl According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0[4]	2	No Studies		[4] - Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.38
Summary Table for Anaerobic Biodegradation Rate Constants for Cumene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		0 [2]	1	[2] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.39
Summary Table for Anaerobic Biodegradation Rate Constants for Dioxane According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.40
Summary Table for Anaerobic Biodegradation Rate Constants for Methanol According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0067	5	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.034[1] (0.043; 0.0022; 0.0089; 0.0039; 0.072; 0.072)	4	[1]- 1 Site 6 studies; No redox regime given
				0.034 [4] (0.028*; 0.030*; 0.054*; 0.036*; 0.016; 0.029*;0.039; 0.039)	1, 6, 7	[4] 1 site; 8 studies *-No redox regime given
	6-8	0.089 [5]	3	0.071[2]	1	[2] - No redox regime given
				0.067[3]	1	[3] - No redox regime given
				0.34	3	[5] Meth/SO_4
				0.058 (0.1*; 0.016**)	4	* - 24 days lag
						** - 30 days lag
	> 8	No Studies		No Studies		

Table D.41
Summary Table for Anaerobic Biodegradation Rate Constants for Nitrobenzene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0037	1	0.0602[2] (0.0037 [2a]; 0.0037-0.23 [2a])	1	[2] - 1 site 2 studies [2a] - Fe reducing
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.42
Summary Table for Anaerobic Biodegradation Rate Constants for Pyridine According to EPA Protocol (Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.010[1] (0.020*, 0)	2, 1	0.014**	2	[1] 1 site; 2 studies * - 90 days lag ** - 30 days lag
	> 8	No Studies		No Studies		

Table D.43
Summary Table for Anaerobic Biodegradation Rate Constants for Styrene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table D.44
Summary Table for Anaerobic Biodegradation Rate Constants for 1,3,5-Trimethylbenzene According to EPA Protocol (Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0 [1]	1	0 [2]	1	[1] Meth/SO_4
						[2] Fe
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

APPENDIX E
FIELD STUDIES FOR ALL COMPOUNDS

Table E.1
Summary Table for Anaerobic Biodegradation Rate Constants for Benzene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0[1]	16	No Studies		[1] Meth/SO_4/Fe
	6-8	0	21	0.0063 [7]	31	[7] No Redox Regime Given
		0.002 [3] (0-0.002;0.002-0.004)	7	0.00134[4] (0.0017; 0.0022; 0.00011)	28	[3] 1 site 2 studies for Meth/NO_3/SO_4
						[4] 1 site 3 studies for Fe
		0.017 [5]	10			[5] Meth/Fe/Mn
		0 [6]	22			[6] Meth/SO_4/Fe
		0.0001075 [2] (0; 0; 0; 0.00043)	30			[2] 1 site; 4 studies for Meth/NO_3/SO_4
		0.00714	29			
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0 [10]	23	[10] SO_4/Fe
	6-8	0.005 [9] (0.01; 0)	25	0.0308 [8] (0.0072-0.046; 0.038; 0.028)	25	[9] 1 site; 2 studies
		0	30			[8] 1 site; 3 studies
	> 8	No Studies		No Studies		

Table E.2
Summary Table for Anaerobic Biodegradation Rate Constants for Toluene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.043 [1]	15	0 [11]	16	[11] No Redox Regime Given
		0	18			[1] Meth/SO_4/Fe
	6-8	0.042 [2] (0.067; 0.026; 0.053; 0.023)	30	0.0024 [3] (0.00099; 0.0039; 0.0023)	28	[2] 1 site; 4 studies for Meth/NO_3/SO_4
						[3] 1 site; 3 studies for Fe
		0.186	27	0.019 [4]	31	[4] No Redox Regime Given
		0.0532 [18] (0.1[19]; 0.0064)	1	0.066	20	[18] 1 site; 2 studies one with [19] Meth/SO_4/Fe
				0.083 [23]	1	[5] Meth/SO_4/Fe
		0.042 [7] (0.053-0.067; 0.023-0.026)	4			[7] 1 site; 2 studies for Meth/NO_3/SO_4
						[23] NO_3/SO_4
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.0086[8] (0.0052-0.012)	23	[8] SO_4/Fe
	6-8	0.003	24	0.027[9] (0.023; 0.031)	25	[9] 1 site; 2 studies
				0.045	24	
		0.032[10] (0.05; 0.013)	29	0.091	6	[10] 1 site; 2 studies
		0.011 [27]	9	0.018 (0.0075-0.03)	7	[27] SO_4/Fe
	> 8	No Studies		No Studies		

Table E.3
Summary Table for Anaerobic Biodegradation Rate Constants for Ethylbenzene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0.0066 [1] (0.011; 0.0024; 0.0099; 0.0031)	19	0.00187 [2] (0.0032; 0.00060; 0.0018)	17	[1] 1 site; 4 studies for Meth/NO_3/SO_4
						[2] 1 site; 3 studies for Fe
		0.00675 [3] (0.003-0.011; 0.003-0.010)	5	0.019 [6]	20	[3] 1 site; 2 studies for Meth/NO_3/SO_4
		0.025[15] (0.0011[15a]; 0.028*[15a]; 0 [15b]; 0.0053 [15c]; 0.067 [15c])	1			[15] 1 site; 4 studies; [15a] Meth; [15b] Meth/NO_3; [15c] Meth/SO_4 ; * 4 days lag
						[5] Meth/SO_4 /Fe
		0	12			[6] No Redox Regime Given
		0 [7]	13			[7] Meth/SO_4 /Fe
		0.024[5]	11			
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0031	14	0.012 [4] (0; 0.029; 0.009; 0.010)	14, 15	[4] 1 site; 4 studies
		0.04 [8] (0.03; 0.05)	18	0 [13]	4	[13] SO_4/Fe
						[8] 1 site; 2 studies
	> 8	No Studies		No Studies		

Table E.4
Summary Table for Anaerobic Biodegradation Rate Constants for m-Xylene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.057 [1]	8	No Studies		[1] Meth/SO_4/Fe
	6-8	0.0077 [2] (0.0037; 0.014; 0.0083; 0.0046)	13	0.00203[3] (0.0033; 0.0012; 0.0016)	14	[2] 1 site; 4 studies for Meth/NO_3/SO_4
						[3] 1 site; 3 studies for Fe
		0.121 [4] (0; 0.32 [4a]; 0.044)	1	0.019 [5]	15	[4] 1 site; 3 studies [4a] Meth/SO_4
						[5] No Redox Regime Given
		0 [6]	10			[6] Meth/SO_4/Fe
		0.019 [7] (0.004-0.008; 0.005-0.014)	5			[7] 1 site; 2 studies for Meth/NO_3/SO_4
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.003	11	0.024	11	
		0.06 [8] (0.02; 0.1)	12	0.050	9	[8] 1 site; 2 studies
				0.0143 [9]	6	[9] SO_4/Fe 121 days lag
	> 8	No Studies		No Studies		

Table E.5
Summary Table for Anaerobic Biodegradation Rate Constants for o-Xylene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.029[6]	11	0[1]	12	[1]- No redox regime given [6] - Meth/SO_4/Fe
	6-8	0.0043	19	0.063[2]	23	[2]- No redox regime given
		0	13	0.0015[3] (0.0022; 0.0015; 0.0082)	20	[3] - Fe reducing
		0.00795[4] (0.004-0.011; 0.009-0.016; 0.004; 0.015; 0.0011; 0.0086)	6, 22			[4] - 1 site 6 studies for Meth/NO_3/SO_4
		0[5]	16			[5] - Meth/SO_4/Fe
	> 8	No Studies		No Studies		
> 15	< 6	0	14	No Studies		
	6-8	0.21	21	0.16*	7	* - 17 days lag
		0.003	17	0.077*	15	* - 17 days lag
				0.02	17	
				0	9	
	> 8	No Studies		No Studies		

Table E.6
Summary Table for Anaerobic Biodegradation Rate Constants for p-Xylene According to EPA Protocol
(Field Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	**Ref.**	**Rate (1/day)**	**Ref.**	
# 15	< 6	0.057[1]	5	No Studies		[1]- Meth/SO_4/Fe
	6-8	0.0043	12	0.019[4]	13	[2]- Meth/SO_4/Fe
		0[2]	6			[4]- No redox regime given
		0.007[3] (0.005-0.014; 0.002-0.010; 0.0094; 0.0024; 0.0051; 0.0096)	3, 10	0.0015[5] (0.00085; 0.0019; 0.0018)	9	[3] - 1 Site 6 studies for Meth/NO_3/SO_4 [5] - 1 Site 3 studies for Fe
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.05 (0.02;0.08)	10	0.016[6] (0; 0.032)	8	[6] - 1 Site 2 studies
		0.0029	8	0.0143*	4	* - 121 days lag
				0.0053 (0.0023- 0.0083)	7	
	> 8	No Studies		No Studies		

Table E.7
Summary Table for Anaerobic Biodegradation Rate Constants for Carbon Tetrachloride According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.11	1	No Studies		
	6-8	0.32 (0.15-0.49)	2	0.0602 [1] (0.0037; 0.0037-0.23)	2	[1] 1 site; 2 studies for Fe
		0.21	1			
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		1.73 [2]	3	[2] NO_3/SO_4
	> 8	No Studies		No Studies		

Table E.8
Summary Table for Anaerobic Biodegradation Rate Constants for Chloroform According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0.03	1	[1] No Redox Regime Given *20-30 days lag
	> 8	No Studies		No Studies		

Table E.9
Summary Table for Anaerobic Biodegradation Rate Constants for 1,2-Dichloroethane According to EPA Protocol (Field Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0076 (0.0042-0.011)	1	No Studies		
	> 8	No Studies		No Studies		

Table E.10
Summary Table for Anaerobic Biodegradation Rate Constants for Dichloromethane According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0.0064	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.11
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 1, 2, 2, -Tetrachloroethane According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.12
Summary Table for Anaerobic Biodegradation Rate Constants for Tetrachloroethylene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0	4	No Studies		
	6-8	0.000735 (0.00068-0.00079)	1	0.00405 [1] (0.0035-0.0046)	5	[1] NO_3/Fe/SO_4/Meth
		0 [2]	8	0 [3]	3	[2] Meth/SO_4/Fe
						[3] Fe/NO_3 /Mn
		0.0109 [4] (0; 0.0097-0.034)	3			[4] 1 site; 2 studies
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.003 [5]	7	No Studies		[5] No Redox Regime Given
	> 8	No Studies		No Studies		

Table E.13
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,1-Trichloroethane According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.011 [1] (0; 0.022)	3	No Studies		[1] 1 site; 2 studies
	6-8	0.0013	1	0 [4]	4	[4] Fe/NO_3
		0 [2]	8	0.010 [3]	5	[2] Meth/SO_4/Fe
		0.041*	5			[3] Fe
		0.0375 (0.029-0.046)	4			*30 days lag
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0.003 [5]	7	[5] No Redox Regime Given
	> 8	No Studies		No Studies		

Table E.14
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,2 -Trichloroethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.15
Summary Table for Anaerobic Biodegradation Rate Constants for Trichloroethylene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0	9	No Studies		
	6-8	0.00062 (0.00045-0.00079)	5	0.0023[1] (0.0017-0.0029)	4	[1] SO_4/Fe
		0	12	0.0036 [2] (0.00014-0.0071)	3	[2] SO_4/Fe
		0.0034 [4] (0.0047;0.00082; 0.0047)	15	[3] 0.00086	6	[3] Fe/ Meth/SO_4 [4] 1 site; 3 studies for Meth/SO_4
		0.0023 [6] (0.0011;0.0034; 0.0010;0.0036; 0.0025)	20, 21	0.00074 [5] (0.00019-0.0024; 0.00014-0.00024)	13	[5] 1 site; 2 studies with No Redox Regime Given [6] 1 site; 5 studies for Meth/SO_4
		0 [7]	8	0.00137[8] (0.00082; 0.0033; 0.0014)	16	[7] Meth/Fe/SO_4 [8] 1 site; 3 studies for NO_3/Fe/SO_4 /Meth
				[9] (0.0016; 0.0015; 0.0011)	17	[9] 1 site; 3 studies for Fe
				0.0033 [10] (0.0038; 0.0033; 0.0027)	21	[10] 1 site; 3 studies for SO_4/Fe
	> 8	No Studies		No Studies		

Table E.15 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Trichloroethylene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
	6-8	No Studies		0.00069 [11] (0.00059-0.00079)	14	[11] Fe/Meth/SO_4
				0.003 [12]	11	[12] No Redox Regime Given
				0.0015[13] (0.0026; 0.0005)	2	[13] 1 site; 2 studies with No Redox Regime Given
	> 8	No Studies		No Studies		

Table E.16
Summary Table for Anaerobic Biodegradation Rate Constants for Vinyl Chloride According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.00093 (0.00086-0.0010)	2	0.0008[1] (0.0012; 0.0013; 0)	3	[1] - 1 site 3 studies for NO_3/Fe/SO_4/Meth
		0.00297 [2] (0.0024; 0.0060; 0.00049)	4			[2] 1 site; 3 studies for Meth/SO_4
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.17
Summary Table for Anaerobic Biodegradation Rate Constants for Phenol According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0	6	0.0135[1] (0; 0.027*)	6	[1] 1 Site 2 studies of Fe, * - 0-70 days lag
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.032	2	No Studies		
	> 8	No Studies		No Studies		

Table E.18
Summary Table for Anaerobic Biodegradation Rate Constants for o-Cresol According to EPA Protocol
(Field Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0[1]	4	No Studies		[1] - Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.034	2	No Studies		
	> 8	No Studies		No Studies		

Table E.19
Summary Table for Anaerobic Biodegradation Rate Constants for m-Cresol According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.033	2	No Studies		
	> 8	No Studies		No Studies		

Table E.20
Summary Table for Anaerobic Biodegradation Rate Constants for p-Cresol According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.048	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.21
Summary Table for Anaerobic Biodegradation Rate Constants for 2,4-Dichlorophenol According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.027	4	0[1]	4	[1] - Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.22
Summary Table for Anaerobic Biodegradation Rate Constants for 2,4,6-Trichlorophenol According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.033	2	No Studies		
	> 8	No Studies		No Studies		

Table E.23
Summary Table for Anaerobic Biodegradation Rate Constants for Pentachlorophenol According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0	2	No Studies		
	> 8	No Studies		No Studies		

Table E.24
Summary Table for Anaerobic Biodegradation Rate Constants for Trichlorofluoromethane According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0016	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.25
Summary Table for Anaerobic Biodegradation Rate Constants for Dichlorodifluoromethane According to EPA Protocol (Field Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		0	1	[1] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.26
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,2-Trichloro-1,2,2-trifluoroethane According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.27
Summary Table for Anaerobic Biodegradation Rate Constants for Acetone According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.28
Summary Table for Anaerobic Biodegradation Rate Constants for Methyl Ethyl Ketone According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.29
Summary Table for Anaerobic Biodegradation Rate Constants for Methyl Isobutyl Ketone According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.30
Summary Table for Anaerobic Biodegradation Rate Constants for Acetic Acid According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.31
Summary Table for Anaerobic Biodegradation Rate Constants for Phenylacetic Acid According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.32
Summary Table for Anaerobic Biodegradation Rate Constants for Acenaphthene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0043	1	No Studies		
	> 8	No Studies		No Studies		

Table E.33
Summary Table for Anaerobic Biodegradation Rate Constants for Fluorene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.00030[1]	1	[1] - No redox regime given
	6-8	No Studies		0.00145[2] (0.0013 - 0.0016)	4	[2] - No redox regime given
	> 8	No Studies		No Studies		

Table E.34
Summary Table for Anaerobic Biodegradation Rate Constants for 1 - Methylnaphthalene According to EPA Protocol (Field Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.057 [1]	4	No Studies		[1] Meth/SO_4 /Fe
	6-8	0	5	0.00031 [2]	2	[2] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0		0.00054 [3] (0.00040-0.00068)		[3] No Redox Regime Given
	> 8	No Studies		No Studies		

Table E.35
Summary Table for Anaerobic Biodegradation Rate Constants for Naphthalene According to EPA Protocol (Field Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.026 [1]	7	No Studies		[1] Meth/SO_4/Fe
		0	11			
	6-8	0 [5]	10	0.0063 [4]	15	[4] No Redox Regime Given
						[5] Meth/Fe/NO_3
		0	12	0 [6]	8	[6] No Redox Regime Given
				0.0018 [7] (0.0015-0.0021)	14	[7] No Redox Regime Given
				0.0050 [8]	12	[8] Fe
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.03 [2] (0.017-0.043)	13	[2] SO_4/Fe
				0.00018 [3]	4	[3] No Redox Regime Given
	6-8	0	5	No Studies		
	> 8	No Studies		No Studies		

Table E.36
Summary Table for Anaerobic Biodegradation Rate Constants for Phenanthrene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.37
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1'Biphenyl According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0[3]	2	0.019[1]	3	[1] - No redox regime given [3] - Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.00032[2]	1	[2] - No redox regime given
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.38
Summary Table for Anaerobic Biodegradation Rate Constants for Cumene According to EPA Protocol (Field Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0 [1]	1	No Studies		[1] Meth/SO_4
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.39
Summary Table for Anaerobic Biodegradation Rate Constants for Dioxane According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.40
Summary Table for Anaerobic Biodegradation Rate Constants for Methanol According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.41
Summary Table for Anaerobic Biodegradation Rate Constants for Nitrobenzene According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0037	1	0.0037 [1] (0.0037 [1a]; 0.0037 [1a]; 0.0037 [1b])	1	[1] - 1 site 3 studies [1a] - NO_3/Mn [1a] - Fe reducing
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.42
Summary Table for Anaerobic Biodegradation Rate Constants for Pyridine According to EPA Protocol
(Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table E.43
Summary Table for Anaerobic Biodegradation Rate Constants for Styrene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0 [1]	1	[1] No Redox Regime Given
	> 8	No Studies		No Studies		

Table E.44
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 3, 5-Trimethylbenzene According to EPA Protocol (Field Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0	4	0	3	
				0.0039	2	
	> 8	No Studies		No Studies		

APPENDIX F
LABORATORY AND FIELD STUDIES FOR ALL COMPOUNDS

Table F.1
Summary Table for Anaerobic Biodegradation Rate Constants for Benzene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0	20	0 [1]	15	[1] No Redox Regime Given
		0 [18]	16			[18] Meth/SO_4/Fe
	6-8	0.0015[1]	9	0.0041	6	[2] Meth/Fe/Mn
		0	21	0.0063 [19]	31	[19] No Redox Regime Given
		0.002 [20] (0-0.002;0.002-0.004)	7	0.00134 [21] (> 0.0017; 0.0022; 0.00011)	28	[20] 1 site 2 studies for Meth/NO_3/SO_4
						[21] 1 site 3 studies for Fe
		0.017 [22]	10			[22] Meth/Fe/Mn
		0 [24]	22			[24] Meth/SO_4/Fe
		0.0001075 [23] (0; 0; 0; 0.00043)	30			[23] 1 site; 4 studies for Meth/NO_3/SO_4
		0.00714	28			
		0 [3]	2	0.047*	11	[3] Meth/SO_4
						*8 days lag
		0.052*	11			*21 days lag
		0.071 [14]	27	0 [11]	3	[11] No Redox Regime Given
						[14] Meth/Fe

Table F.1 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Benzene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15 (cont.)	6-8 (cont.)	0.0 [6] (0; 0)	1	0.0065 [13]	28	[6] 1 site 2 studies of Meth/SO_4 and Meth/NO_3
						[13] Fe
		0 [7]	18	0 [12]	2	[7] Meth/Fe/NO_3
		0.031	3			[12] Fe
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0	23	
	6-8	0	7	0.0308 [26] (0.0072-0.046; 0.038; 0.028)	25	[26] 1 site; 3 studies
				0.0041 [8]	6	[8] SO_4/Fe; 121 days lag
				0.0237 [15]	6	[15] SO_4/Fe; 184 days lag
		0	14	0	4	
		0	8	0.003	8	
		0.0074*	26			*140 days lag
		0.0 [17] (0;0)	13			[17] Meth/SO_4
		0.005 [25] (0.01; 0)	25			[25] 1 site; 2 studies
		0	30			
	> 8	No Studies		No Studies		

Table F.2
Summary Table for Anaerobic Biodegradation Rate Constants for Toluene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0	18	0 [11]	16	[11] No Redox Regime Given
		0.043 [31]	15			[31] Meth/SO_4/Fe
	6-8	0.043[12]	27	0.016 [13]	10	[12] Meth/Fe
						[13] No Redox Regime Given
		0.093[14]	8	0.087 [15]	14	[14] Meth/Fe/Mn
						[15] Fe
		0 [16]	19	0.0045 [17]	17	[16] Meth/Fe/NO_3
						[17] No Redox Regime Given
		0.0532 [18] (0.1[19]; 0.0064)	1	0.010 [20]	28	[18] 1 site; 2 studies one with [19] Meth/SO_4/Fe
						[20] Fe
		0 [21] (0 [22]; 0)	1	0.083 [23]	1	[21] 1 site; 2 studies one with [22] Meth/NO_3
		0.10 [24]	2			[23] NO_3/SO_4
						[24] Meth/Fe/Mn
		0.042 [32] (0.067; 0.026; 0.053; 0.023)	30	0.0024 [33] (0.00099; 0.0039; 0.0023)	28	[32] 1 site; 4 studies for Meth/NO_3/SO_4
						[33] 1 site; 3 studies for Fe
		0.186	27	0.019 [34]	31	[34] No Redox Regime Given
		0 [35]	21	0.066	20	[35] Meth/SO_4/Fe
		0.042 [37] (0.053-0.067; 0.023-0.026)	4			[37] 1 site; 2 studies for Meth/NO_3/SO_4
	> 8	No Studies		No Studies		

Table F.2 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Toluene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
> 15	< 6	No Studies		0.0086 [38] (0.0052-0.012)	23	[38] SO_4/Fe
	6-8	0	7	0.11	3	
		0.034 [25] (0.036*[1]; 0; 0.032*[2]; 0.06*[3]; 0.012; 0.063)	11	0.0446 [26]	9	[25] 1 site; 6 studies;*[1] 208 days lag; *[2] 99 days lag;*[3]302 days lag [26] SO_4/Fe
		0.0115 [27]	9	0.011	22	[27] SO_4/Fe
		0.028 [28] (0.036; 0.020)	5	0.027 [39] (0.023; 0.031)	25	[28] 1 site; 2 studies
		0.0098	4	0.091	6	[29] No Redox Regime Given
		0	12	0.018 (0.0075-0.03)	7	[39] 1 site; 2 studies
		0.018	28	0.045	24	
		0.003	24			
		0.032 [40] (0.05; 0.013)	29			[40] 1 site; 2 studies
		0	14			
	> 8	No Studies		No Studies		

Table F.3
Summary Table for Anaerobic Biodegradation Rate Constants for Ethylbenzene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0 [9]	2	0	2	[9] Meth/SO_4
	6-8	0.0055[10]	7	0[11]	9	[10] Meth/Fe/Mn
						[11] No Redox Regime Given
		0.0066 [1] (0.011; 0.0024; 0.0099; 0.0031)	19	0.00187 [2] (0.0032; 0.00060; 0.0018)	17	[1] 1 site; 4 studies for Meth/NO_3/SO_4
						[2] 1 site; 3 studies for Fe
		0.00675 [3] (0.003-0.011; 0.003-0.010)	5	0.019 [6]	20	[3] 1 site; 2 studies for Meth/NO_3/SO_4
		0.025[15] (0.0011[15a]; 0.028*[15a]; 0 [15b]; 0.0053 [15c]; 0.067 [15c])	1			[15] 1 site; 4 studies; [15a] Meth; [15b] Meth/NO_3; [15c] Meth/SO_4 ; * 4 days lag
						[12] 1 site 2 studies; [12a] Meth; [12b] Meth/NO_3
		0[12] (0 [12a]; 0[12b])	1			[5] Meth/SO_4 /Fe
						[6] No Redox Regime Given
		0 [7]	13			[7] Meth/SO_4 /Fe
		0.024[5]	11			[5] Meth/SO_4 /Fe
	> 8	No Studies		No Studies		

Table F.3 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Ethylbenzene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
> 15	< 6	No Studies		No Studies		
	6-8	0	10	0 [13]	4	[13] SO_4/Fe
		0.0031	14	0.012 [4] (0; 0.029; 0.009; 0.010)	14, 15	[4] 1 site; 4 studies
		0.04 [8] (0.03; 0.05)	18			[8] 1 site; 2 studies
		0.0029	5	0.0019 [14]	8	[14] SO_4/Fe
		0.0076*	16			*140 days lag
		.29 [15] (0.12; 0.46)	6			[15] 1 site; 2 studies
	> 8	No Studies		No Studies		

Table F.4
Summary Table for Anaerobic Biodegradation Rate Constants for m-Xylene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.057 [1]	8	0 [11]	2	[1] Meth/SO_4/Fe
		0 [10]	2			[10] Meth/SO_4
						[11] Fe
	6-8	0.0077 [2] (0.0037; 0.014; 0.0083; 0.0046)	13	0.00203[3] (0.0033; 0.0012; 0.0016)	14	[2] 1 site; 4 studies for Meth/NO_3/SO_4
						[3] 1 site; 3 studies for Fe
		0	1			
		0.121 [4] (0; 0.32 [4a]; 0.044)	1	0.019 [5]	15	[4] 1 site; 3 studies; [4a] Meth/SO_4
						[5] No Redox Regime Given
		0 [6]	10			[6] Meth/SO_4/Fe
		0.019 [7] (0.004-0.008; 0.005-0.014)	5			[7] 1 site; 2 studies for Meth/NO_3/SO_4
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.003	11	0.024	11	
		0	7	0.0204[12]	6	[12] SO_4/Fe
		0.0006	5	0.17*	3	*17 days lag
		0.06 [8] (0.02; 0.1)	12	0.050	9	[8] 1 site; 2 studies
				0.0143 [9]	6	[9] SO_4/Fe; 121 days lag
	> 8	No Studies		No Studies		

Table F.5
Summary Table for Anaerobic Biodegradation Rate Constants for o-Xylene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.029[6]	11	0[1]	12	[1]- No redox regime given
				0[7]	2	[6] - Meth/SO_4/Fe
						[7] - Fe reducing
	6-8	0.0043	19	0.063[2]	23	[2]- No redox regime given
				0[6]	4	[6] - No redox regime given
		0	13	0.0015[3] (0.0022; 0.0015; 0.0082)	20	[3] - Fe reducing
		0.00795[4] (0.004-0.011; 0.009-0.016; 0.004; 0.015; 0.0011; 0.0086)	6, 22			[4] - 1 site 6 studies for Meth/NO_3/SO_4
		0[5]	16			[5] - Meth/SO_4/Fe
		0	1			
		0.071 [8]	19			[8] - Meth/Fe
		0.0091 [9]	8			[9] -Meth/Fe/Mn
		0 [10]	13			[10] -Meth/Fe/NO_3
	> 8	No Studies		No Studies		

Table F.5 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for o-Xylene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
	6-8	0.21	21	0.16*	7	* - 17 days lag
		0.003	17	0.077*	15	* - 17 days lag
		0.0006	6	0.02	17	
		0	10	0	9	*[11] - SO_4/Fe; 37 days lag
		0.0087*	18	0.00559*[11]	5	* - 140 days lag
				0	3	
	> 8	No Studies		No Studies		

Table F.6
Summary Table for Anaerobic Biodegradation Rate Constants for p-Xylene According to EPA Protocol
(Field and Laboratory Studies)

		Methanogenic		Sulfate Reducing		
Temp. (°C)	**pH**	**Rate (1/day)**	**Ref.**	**Rate (1/day)**	**Ref.**	**Comments**
# 15	< 6	0.057[1]	5	0[9]	1	[1]- Meth/SO_4/Fe
						[9] - Fe
		0[7]	1			[7]- Meth/SO_4
	6-8	0.0043	12	0.019[4]	13	[2]- Meth/SO_4/Fe
		0.057[8]	12			[8]- Meth/Fe
		0.0006	3			
		0[2]	6			[4]- No redox regime given
		0.007[3] (0.005-0.014; 0.002-0.010; 0.0094; 0.0024; 0.0051; 0.0096)	3, 10	0.0015[5] (0.00085; 0.0019; 0.0018)	9	[3] - 1 Site 6 studies for Meth/NO_3/SO_4
						[5] - 1 Site 3 studies for Fe
	> 8	No Studies		No Studies		

Table F.6 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for p-Xylene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	**Ref.**	**Rate (1/day)**	**Ref.**	
> 15	< 6	No Studies		No Studies		
	6-8	0.05 (0.02;0.08)	10	0.016[6] (0; 0.032)	8	[6] - 1 Site 2 studies
				0.17*	2	* - 21 days lag
		0.0029	8	0.0143*	4	* - 121 days lag
				0.0053 (0.0023- 0.0083)	7	
	> 8	No Studies		No Studies		

Table F.7
Summary Table for Anaerobic Biodegradation Rate Constants for Carbon Tetrachloride According to EPA Protocol (Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.11	1	No Studies		
	6-8	0.32 (0.15-0.49)	2	0.0602 [1] (0.0037; 0.0037-0.23)	2	[1] 1 site; 2 studies for Fe
		0.21	1			
		0.23	2	0 [3]	2	[3] Fe/NO_3/Mn
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		1.73 [2]	3	[2] NO_3/SO_4
	> 8	No Studies		No Studies		

Table F.8
Summary Table for Anaerobic Biodegradation Rate Constants for Chloroform According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.01562 [2] (0.025*[a]; 0.02*[a]; 0.025*[a]; 0.004*[b]; 0.0041*[b])	2	[2] 1 site; 5 studies with No Redox Regime Given *[a] 56 days lag *[b] 112 days lag
	6-8	No Studies		0.142 [3] (0.099; 0.25*; 0.033; 0.099; .25*; .12)	2	[3] 1 site; 6 studies with No Redox Regime Given *14 days lag
				0.03	1	[1] No Redox Regime Given *20-30 days lag
	> 8	No Studies		No Studies		

Table F.9
Summary Table for Anaerobic Biodegradation Rate Constants for 1,2-Dichloroethane According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0076 (0.0042-0.011)	1	No Studies		
	> 8	No Studies		No Studies		

Table F.10
Summary Table for Anaerobic Biodegradation Rate Constants for Dichloromethane According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0064	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.11
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 1, 2, 2, -Tetrachloroethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.12
Summary Table for Anaerobic Biodegradation Rate Constants for Tetrachloroethylene According to EPA Protocol (Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0	4	No Studies		
	6-8	0.000735 (0.00068-0.00079)	1	0.00405 [1] (0.0035-0.0046)	5	[1] NO_3/Fe/SO_4/Meth
		0 [2]	8	0 [3]	3	[2] Meth/SO_4/Fe
		0.071[6]	2			[3] Fe/NO_3 /Mn
		0 [7]	3			[6] Meth/SO_4
						[7] Meth/Fe/NO_3/Mn
		0.0109 [4] (0; 0.0097-0.034)	3			[4] 1 site; 2 studies
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.00073	2	
	6-8	0.003 [5]	7	0.054[8]	6	[5] No Redox Regime Given
		0.0084	2			[8] No Redox Regime Given
				0.0065[9] (0; 0.013)	9	[9] 1 site; 2 studies No Redox Regime Given
	> 8	No Studies		No Studies		

Table F.13
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,1-Trichloroethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.011 [1] (0; 0.022)	3	No Studies		[1] 1 site; 2 studies
	6-8	0.0013	1	0 [4]	4	[4] Fe/NO_3
		0.0037	4	0 [6]	4	[6] Fe/NO_3/Mn
		0 [2]	8	0.010 [3]	5	[2] Meth/SO_4/Fe
		0.041*	5			[3] Fe
		0.0375 (0.029-0.046)	4			*30 days lag
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0.003 [5]	7	[5] No Redox Regime Given
		0.0092 [7] (0.015; 0.0034)	1	0.0092[8] (0.015; 0.0034)	1	[7] 1 site; 2 studies
						[8] 1 site; 2 studies
				0.0099 [9]	6	[9] No Redox Regime Given
	> 8	No Studies		No Studies		

Table F.14
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 1, 2-Trichloroethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.15
Summary Table for Anaerobic Biodegradation Rate Constants for Trichloroethylene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0	9	No Studies		
	6-8	0.00062 (0.00045-0.00079)	5	0.0023[1] (0.0017-0.0029)	4	[1] SO_4/Fe
		0	12	0.0036 [2] (0.00014-0.0071)	3	[2] SO_4/Fe
		0.0034 [4] (0.0047; 0.00082; 0.0047)	15	[3] 0.00086	6	[3] Fe/ Meth/SO_4 [4] 1 site; 3 studies for Meth/SO_4
		0.0023 [6] (0.0011; 0.0034; 0.0010; 0.0036; 0.0025)	20, 21	0.00074 [5] (0.00019-0.0024; 0.00014-0.00024)	13	[5] 1 site; 2 studies with No Redox Regime Given [6] 1 site; 5 studies for Meth/SO_4
		0 [7]	8	0.0013[8] (0.00082; 0.0033; 0.0014)	16	[7] Meth/Fe/SO_4 [8] 1 site; 3 studies for NO_3/Fe/SO_4 /Meth
				0.014 [9] (0.0016; 0.0015; 0.0011)	17	[9] 1 site; 3 studies for Fe
				0.0033 [10] (0.0038; 0.0033; 0.0027)	21	[10] 1 site; 3 studies for SO_4/Fe
		0 [14]	8	0.010 [15]	19	[14] Meth/Fe/NO_3 /Mn [15] Fe
	> 8	No Studies		No Studies		

Table F.15 (continued)
Summary Table for Anaerobic Biodegradation Rate Constants for Trichloroethylene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
> 15	< 6	No Studies		0[16] (0; 0; 0; 0)	10	[16] 1 site; 4 studies with No Redox Regime Given
				0.0011 [17]	18	[17] SO_4/Fe
	6-8	0.016 [19] (0.011-0.021)	1	0.00069 [11] (0.00059-0.00079)	14	[11] Fe/Meth/SO_4
				[12] 0.003	11	[12] No Redox Regime Given
				0.0015[13] (0.0026; 0.0005)	2	[13] 1 site; 2 studies with No Redox Regime Given
				0.00153 [18] (0.0017; 0; 0.0029)	18	[18] 1 site; 3 studies with SO_4/Fe [19] Meth/Fe/SO_4
		0.039 [20] (0.038*[1]; 0.040*[2])	7	0.0090 [21] (0.0077; 0.0082-0.011)	1	[20] 1 site; 2 studies; *[1] 110 days lag; *[2] 108 days lag [21] 1 site; 2 studies with No Redox Regime Given
		0.013* (0.0020-0.024)	17	0.0029[22] (0.00057-0.005)	4	*112 days lag [22]SO_4/Fe
				0.010	19	
	> 8	No Studies		No Studies		

Table F.16
Summary Table for Anaerobic Biodegradation Rate Constants for Vinyl Chloride According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.00093 (0.00086-0.0010)	2	0.0008[1] (0.0012; 0.0013; 0)	3	[1] - 1 site 3 studies for NO_3/Fe/SO_4/Meth
		0.00297[2] (0.0024; 0.0060; 0.00049)	4			[2] 1 site; 3 studies for Meth/SO_4
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0.0069[3] (0.0082; 0.0057)	1	[3] 1 site; 2 studies with No Redox Regime Given
				0.0082[4]	1	[4] - No Redox Regime Given
	> 8	No Studies		No Studies		

Table F.17
Summary Table for Anaerobic Biodegradation Rate Constants for Phenol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		0.20 [2]	7	[2] - No redox regime given
	6-8	0[7] (0,0[3])	6	0.0135[1] (0; 0.027*)	6	[1] - 1 Site 2 studies of Fe, * - 0-70 days lag
				0[4]	4	[4] - No redox regime given
						[7] 1 site; 2 studies, [3] - Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	0.13*	3	No Studies		* - 50 days lag
	6-8	0.057[6] (0.032, 0.068*,0.071**)	2, 1, 2	No Studies		[6] 1 site; 3 studies, * - 40 days lag, ** - 30 days lag
		0.10[5]	5	No Studies		[5] - Meth/SO_4
	> 8	No Studies		No Studies		

Table F.18
Summary Table for Anaerobic Biodegradation Rate Constants for o-Cresol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0[1] (0; 0)	4	0[3]	3	[1] 1 site; 2 studies for Meth/Fe/NO_3 [3] - No redox regime given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0050	5	No Studies		
		0.033[2] (0.032*; 0.034; 0.034*)	2, 1, 2			[2] 1 site; 3 studies * - 100 days lag
	> 8	No Studies		No Studies		

Table F.19
Summary Table for Anaerobic Biodegradation Rate Constants for m-Cresol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.033	2	No Studies		
		0.0203[1] (0.0029, 0.029*, 0.029*)	3, 2,1			[1] 1 site; 3 studies * - 100 days lag
	> 8	No Studies		No Studies		

Table F.20
Summary Table for Anaerobic Biodegradation Rate Constants for p-Cresol According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.04 (0.035*, 0.048, 0.037*)	1,1,2	No Studies		[1] 1 site; 3 studies * - 100 days lag
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.21
Summary Table for Anaerobic Biodegradation Rate Constants for 2,4-Dichlorophenol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref	Rate (1/day)	Ref	
# 15	< 6	0.015	2	No Studies		
	6-8	0.017	2	0[1] (0, 0)	4	[1] 1 site; 2 studies for Fe/NO_3
		0.027	4			
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.090	5	0.0055	1	
		0.12[4]	3	0[2]	5	[4] - Meth/SO_4
		0.12	1			[2] No Redox Regime Given
	> 8	No Studies		No Studies		

Table F.22
Summary Table for Anaerobic Biodegradation Rate Constants for 2,4,6-Trichlorophenol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.23
Summary Table for Anaerobic Biodegradation Rate Constants for Pentachlorophenol According to EPA Protocol
(Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	1.98e-03 [1] (1.61e-03-2.36e-03)	1	No Studies		[1] - 1 site 2 studies
		1.414e-03[1] (1.01e-03-2.17e-03; 6.86e-04-1.79e-03)	1			
	6-8	1.97e-03 [3] (1.60e-03-2.42e-03; 1.06e-03-2.80e-03)	1	No Studies		[3] - 1 site 2 studies
	> 8	No Studies		No Studies		
> 15	< 6	4.94e-03 (7.38e-03 -2.50e-03)	1	0 [2]	3	[2] No Redox Regime Given
	6-8	0 (0; 0)	4	No Studies		[4] - 1 site 2 studies
		5.09e-03[5] (2.91e-03-7.27e-03)	1			[5] - 1 site 2 studies
		0	2			
		5.75e-03[4] (1.63e-03-2.15e-03; 0.0162-3.0e-03)	1			
	> 8	No Studies		No Studies		

Table F.24
Summary Table for Anaerobic Biodegradation Rate Constants for Trichlorofluoromethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0016	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.25
Summary Table for Anaerobic Biodegradation Rate Constants for Dichlorodifluoromethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref	Rate (1/day)	Ref	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		0	1	[1] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.26
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1,2-Trichloro-1,2,2-trifluoroethane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref	Rate (1/day)	Ref	
# 15	< 6	No Studies		No Studies		
	6-8	0	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.27
Summary Table for Anaerobic Biodegradation Rate Constants for Acetone According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.28
Summary Table for Anaerobic Biodegradation Rate Constants for Methyl Ethyl Ketone According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.29
Summary Table for Anaerobic Biodegradation Rate Constants for Methyl Isobutyl Ketone According to EPA Protocol (Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.30
Summary Table for Anaerobic Biodegradation Rate Constants for Acetic Acid According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.31
Summary Table for Anaerobic Biodegradation Rate Constants for Phenylacetic Acid According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.32
Summary Table for Anaerobic Biodegradation Rate Constants for Acenaphthene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.0043	1	No Studies		
	> 8	No Studies		No Studies		

Table F.33
Summary Table for Anaerobic Biodegradation Rate Constants for Fluorene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0	2	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.00030[1]	1	[1] - No redox regime given
	6-8	0[3]	3	0.00145[2] (0.0013 - 0.0016)	4	[2] - No redox regime given [3] - Meth/NO_3/SO_4
	> 8	No Studies		No Studies		

Table F.34
Summary Table for Anaerobic Biodegradation Rate Constants for 1-Methylnaphthalene According to EPA Protocol (Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	0.057 [1]	4	0 [3]	1	[1] Meth/SO_4 /Fe
		0 [2]	1			[2] Meth/SO_4
						[3] Fe
	6-8	0	5	0.00031 [4]	2	[4] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0		0.00054 [5] (0.00040-0.00068)		[5] No Redox Regime Given
	> 8	No Studies		No Studies		

Table F.35
Summary Table for Anaerobic Biodegradation Rate Constants for Naphthalene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0.026 [1]	7	0[10]	2	[1] Meth/SO_4/Fe
		0 [9]	2			[9] Meth/SO_4
						[10] Fe
		0	11			
	6-8	0 [5]	10	0.0063 [4]	15	[4] No Redox Regime Given
						[5] Meth/Fe/SO_3
		0 [11]	10	0 [12]	1	[11] Meth/Fe/NO_3
						[12] No Redox Regime Given
		0 [13]	3	0 [14]	6	[13] Meth/Fe/Mn
						[14] No Redox Regime Given
		0	12	0 [6]	8	[6] No Redox Regime Given
				0.0018 [7] (0.0015-0.0021)	14	[7] No Redox Regime Given
				0.0050 [8]	12	[8] Fe
	> 8	No Studies		No Studies		
> 15	< 6	0	9	0.03 [2] (0.017-0.043)	13	[2] SO_4/Fe
				0.00018 [3]	4	[3] No Redox Regime Given
				0	8	
	6-8	0	5	No Studies		
	> 8	No Studies		No Studies		

Table F.36
Summary Table for Anaerobic Biodegradation Rate Constants for Phenanthrene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.37
Summary Table for Anaerobic Biodegradation Rate Constants for 1,1'Biphenyl According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0[3] (0, 0)	2	0.019[1]	3	[1] - No redox regime given
						[3] 1 site; 2 studies of Meth/Fe/NO_3
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.00032[2]	1	[2] - No redox regime given
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.38
Summary Table for Anaerobic Biodegradation Rate Constants for Cumene According to EPA Protocol (Field and Laboratory Studies)

Temp. (°C)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0 [1]	1	0 [2]	1	[1] Meth/SO_4
						[2] No Redox Regime Given
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.39
Summary Table for Anaerobic Biodegradation Rate Constants for Dioxane According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0	1	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.40
Summary Table for Anaerobic Biodegradation Rate Constants for Methanol According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	No Studies		No Studies		
	6-8	0.0067	5	No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		0.034[1] (0.043; 0.0022; 0.0089; 0.0039; 0.072; 0.072)	4	[1]- 1 Site 6 studies; No redox regime given
				0.034 (0.028; 0.030; 0.054; 0.036; 0.016; 0.029;0.039; 0.039)	1, 6, 7	[4] 1 site; 8 studies *-No redox regime given
	6-8	0.089 [5]	3	0.071[2]	1	[2] - No redox regime given
				0.067[3]	1	[3] - No redox regime given
				0.34	3	[5] Meth/SO_4
				0.058 (0.1*; 0.016**)	4	* - 24 days lag
						** - 30 days lag
	> 8	No Studies		No Studies		

Table F.41
Summary Table for Anaerobic Biodegradation Rate Constants for Nitrobenzene According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	0.0037 [2] (0.0037; 0.0037)	1	0.00263 [1] (0.0037 [1a]; 0.0037 [1a]; 0.0037 [1b]; 0.0037 [1b]; 0.037-0.23 [1b])	1	[1] - 1 site 5 studies [1a] - NO_3/Mn [1b] - Fe reducing
	> 8	No Studies		No Studies		[2] - 1 site 2 studies
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		

Table F.42
Summary Table for Anaerobic Biodegradation Rate Constants for Pyridine According to EPA Protocol
(Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref	Comments
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0.010[1] (0.020*, 0)	2, 1	0.014**	2	[1] 1 site; 2 studies * - 90 days lag ** - 30 days lag
	> 8	No Studies		No Studies		

Table F.43
Summary Table for Anaerobic Biodegradation Rate Constants for Styrene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic		Sulfate Reducing		Comments
		Rate (1/day)	Ref.	Rate (1/day)	Ref.	
# 15	< 6	No Studies		No Studies		
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	No Studies		0 [1]	1	[1] No Redox Regime Given
	> 8	No Studies		No Studies		

Table F.44
Summary Table for Anaerobic Biodegradation Rate Constants for 1, 3, 5-Trimethylbenzene According to EPA Protocol (Field and Laboratory Studies)

Temp. (ºC)	pH	Methanogenic Rate (1/day)	Methanogenic Ref.	Sulfate Reducing Rate (1/day)	Sulfate Reducing Ref.	Comments
# 15	< 6	0 [1]	1	0 [2]	1	[1] Meth/SO_4
						[2] Fe
	6-8	No Studies		No Studies		
	> 8	No Studies		No Studies		
> 15	< 6	No Studies		No Studies		
	6-8	0	4	0	3	
				0.0039	2	
	> 8	No Studies		No Studies		

APPENDIX G
REFERENCES FOR ALL COMPOUNDS

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