Microbial Fouling Control in Groundwater Extraction and Treatment: A pilot study

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Introduction

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Agenda

- Purpose
- Site Characterization & Background
- Treatment System
- Well Water Quality
- Methods
- Results
- Conclusion
- Additional Studies

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Purpose

- Mitigate fouling in extraction line and pretreatment for groundwater extraction and treatment plant.
- Design phase
- Bench scale pilot test to determine efficacy and fate of biocides and deposit control agents in proposed extraction wells
  - PAA, THPS
  - EDTA, Citric Acid, HEDP, Sodium Metasilicate, Terpolymer
- Organic Fouling
  - Microbial biofilm
  - Biofilm established in a system, biofilm leads to biofouling
  - Chemical inhibitors or heat to address
- Inorganic Fouling:
  - Deposition of an inorganic species: iron, manganese

Example of biofouling[1]

Example of inorganic deposition [2]

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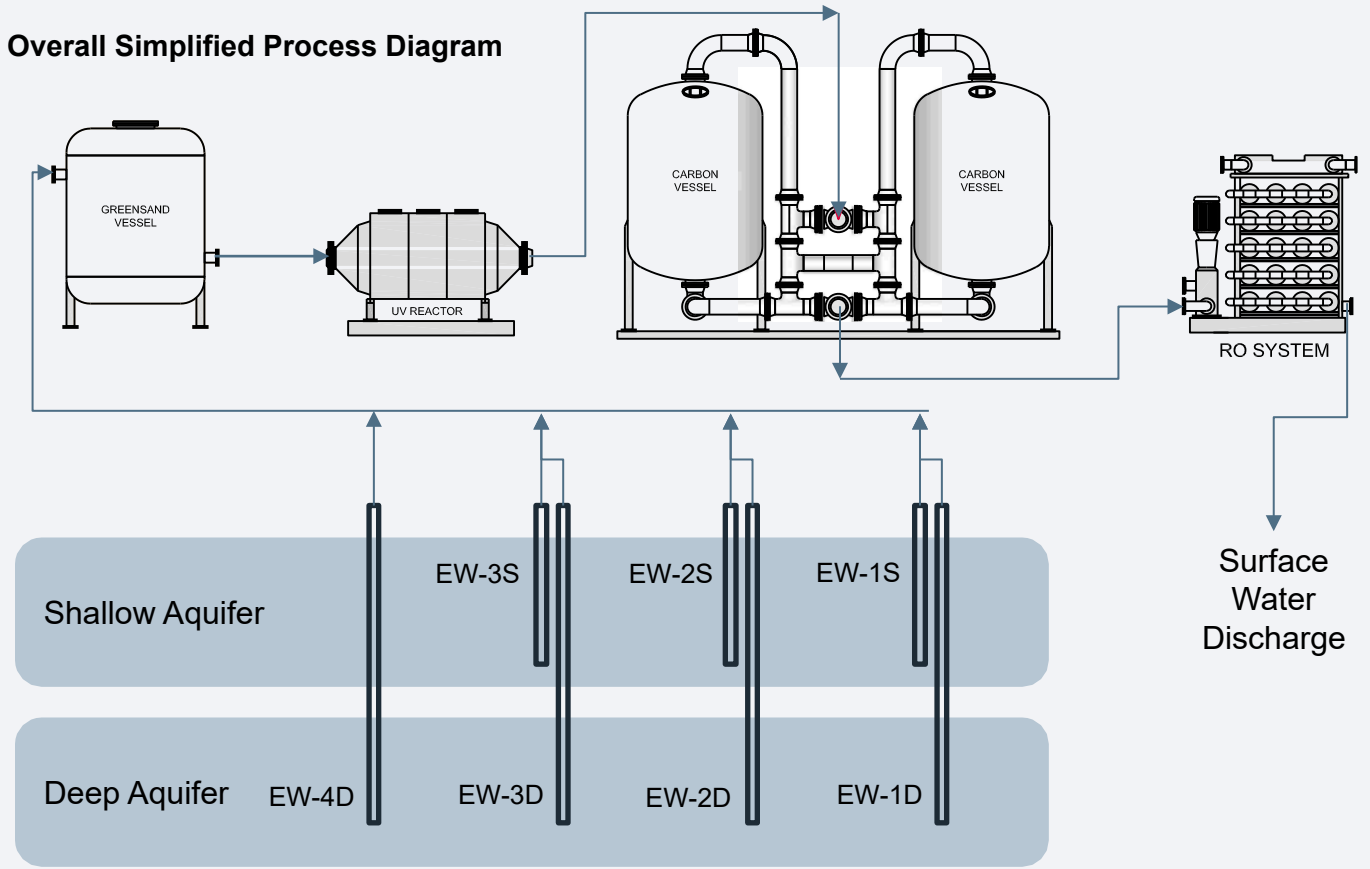
1. https://www.process-worldwide.com/how-biofouling-control-saves-energy-consumption-and-maintenance-costs-a-333506/
2. https://www.reduxtech.com/

Site Characterization

- Southern California Superfund Site
- Proposed Groundwater Extraction and Treatment System (GET) 1.1 MGD
- Multiple miles of extraction pipeline ~20 minute residence time
- 2 aquifer systems and 7 wells
  - Deep Aquifer System (DAS)
  - Shallow Aquifer System (SAS)
- Biological analysis of wells indicated risk of organic biofouling
- Some wells exhibited iron and manganese concentrations up to 2 mg/L.

Treatment System



Well Water Quality

- 7 Extraction Wells (EW) in 4 different locations
- Easiest wells to set up a pilot study were EW-2S/EW-2D
- Organics
  - Fe/Mn oxidizing bacteria
  - SRB bacteria
- Inorganics
  - Fe/Mn

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Well Water Quality

	EW-2S	EW-2D
pH	7	7.8
ORP (mV)	235	-293
Cond (s/cm)	1621	500
DO (mg/L)	1.67	0.21

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Well Water Quality

	Total	Description	EW-1S		EW-1D		EW-2S		EW-2D		EW-3S		EW-3D	
			Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer
Plate Count			>1500	>1501	630	350	>1500	380	>1500	>1500	>1500	>1500	>1500	>1500
Anaerobic Growth %			<10	<10	30	<10	35	20	50	10	50	35	50	<10
Sulfate-reducing Bacteria			Negative	Negative	Positive	Negative	Positive	Positive	Positive	Negative	Positive	Positive	Positive	Negative
SRB Occurance			-	-	Low	-	Low	Very Low	Excessive	-	Excessive	Moderate	Excessive	-
Fe/Mn Oxidizing Bacteria			Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Positve	Negative	Negative
ATP cells/ml Initial			46,000	25,000	155,000	24,000	113,000	40,000	217,000	336,000	146,000	35,000	70,000	158,000
ATP cells/ml 24 hour			75,000	48,000	93,000	47,000	96,000	47,000	130,000	164,000	120,000	41,000	77,000	120,000
Bacteria:														
Acidovorax konjaci	1	Soil bacteria; plant disease												X
Acinetobacter beijerinckii	1							X						
Acinetobacter lwoffii	1		X											
Acinetobacter venetianus	1	Produces emulsans. Role in oil and hc degradation			X									
Acinobacter species	1			X										
Aeromonas specie	3	Facult. Anaerobe; Slime-former; opportunistic pathogen									X	X	X	
Bacillus specie	1								X					
Exiguobacterium aurantiacum	1		X											
Gallionella	1	Aerobic, Fe-oxdizing. Secretes Fe(OH)2, accumulates in wells										X		
Gordonia species	1			X										
Pseudomonas aeruginosa	4	opportunistic pathogen;					X			X	X	X		
Pseudomonas strutzeri	4	Slime-former: dense, leathery biomass			X	X			X					X
Sphingmonas specie	1				X									
LSI			0.24	0.37	0.31	0.28	0.11	0.16	0.35	-0.23	0.51	0.49	0.59	0.42

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Well Water Quality

	Total	Description	EW-1S		EW-1D		EW-2S		EW-2D		EW-3S		EW-3D	
			Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer
Iron/Mn Result														
Dissolved Fe (as Fe^{2+}) mg/l			<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Fe (as Fe) mg/l			0.03	0.04	0.03	0.02	0.05	0.06	0.61	0.07	0.02	0.02	0.04	0.05
Dissolved Fe mg/l				0.71		0.33		0.59		<0.25		2.3		1.41
Total Fe mg/l				0.75		0.34		0.60		<0.25		2.3		1.43
Total Mn mg/l				0.1		0.1		<0.1		<0.1		<0.1		<0.1
Total Mn mg/l				0.003		0.029		0.0011		0.0086		0.37		0.044

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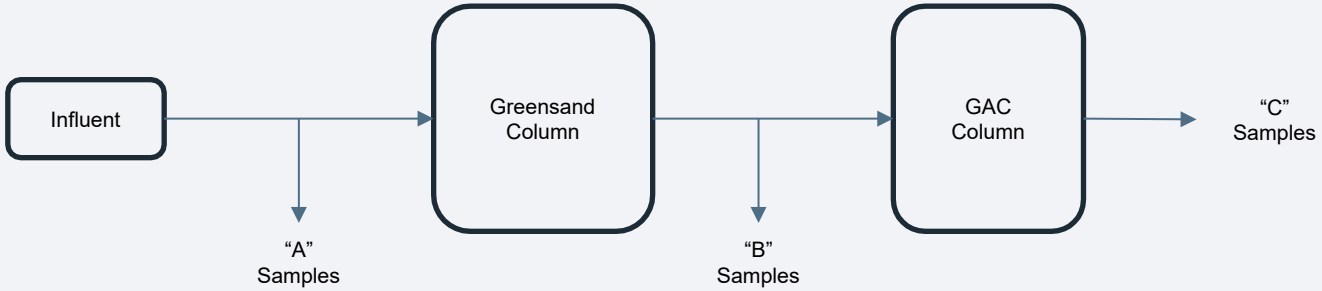
Methods

Figure 1: Bench Scale Process Diagram



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Methods

Methods

Methods

- Aim 1: Biocide Efficacy and Concentration
  - Take well sample with biocide dosed in container
  - Test for residual concentration
  - Take lab analysis samples
  - BART/Dipslide test (7-days)

- Aim 2: Deposit Control Efficacy
  - Take well sample with deposit control chemical dosed in container
  - Aliquot with PAA
  - Spike with Iron
  - Pass through filter and take lab sample
  - Spike sample with sodium hypochlorite
  - Pass through Greensand Column
  - Filter and take sample

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Methods

- Aim 1: Biocide Efficacy and Concentration
  - PAA: 2, 5, 14 ppm
  - THPS: 12, 30, 60 ppm
  - BART/Dipslide 7-days
    - Biological Activity Reaction Test
  - Jar test 20, 60, 240, 480 min

- Aim 2: Deposit Control Efficacy
  - % Filtered through .45/.10 micron filter
  - Understand fate through oxidant media filter (greensand)
  - % Removed through .45/.10 micron filter post greensand
  - Greensand columns mimicking EBCT

Results

	Time (min)	0	1	20	60	120	240	480	demand at 60 min
#4 PAA	PAA	10.4	8.7	9.3	9.1	8.5	4.4	3.7	1.3
High Dose	Fe^{+2}		0.03	0.04	0.00	0.02			
#5 THPS	THPS	9.1	9	8	8		8	5	1.1
Low Dose	Fe^{+2}		0.06	0.07	0.11	0.11			

Citric Acid	EW-2D-D3-001	1830		initial
	EW-2D-D3-001-F45	1780	2.7%	% filtered
	EW-2D-D3-001-F10	1800	1.6%	% filtered
	EW-2D-D3-030	1820	99.5%	% mobile
	EW-2D-D3-030-F45	1780	2.2%	% filtered
	EW-2D-D3-030-F10	1790	1.6%	% filtered
	EW-2D-D3-END	49.9	97.3%	% removed
	EW-2D-D3-END-F45	402	0.0%	% filtered
	EW-2D-D3-END-F10	176	0.0%	% filtered

Results

EDTA	EW-2D-D2-001	1950		initial
	EW-2D-D2-001-F45	1710	12.3%	% filtered
	EW-2D-D2-001-F10	1750	10.3%	% filtered
	EW-2D-D2-030	1910	97.9%	% mobile
	EW-2D-D2-030-F45	1780	6.8%	% filtered
	EW-2D-D2-030-F10	1760	7.9%	% filtered
	EW-2D-D2-END	1100	42.4%	% removed
	EW-2D-D2-END-F45	1070	2.7%	% filtered
	EW-2D-D2-END-F10	1020	7.3%	% filtered

Results

- Biocide
  - Peracetic Acid (PAA)
  - Tetrakis Hydroxymethyl Phosphonium Sulfate (THPS)
- Deposit Control Chemicals
  - EDTA
  - Citric Acid
  - Terpolymer
  - HEDP
  - Sodium Silicate

		PAA				THPS			
		Low Dose	Mid Dose	High Dose		Low Dose	Mid Dose	High Dose	
EW-2S	**B1***	**B2**	**B3**	**B4**		**B5**	**B6**	**B7**	
		(Additional days elapsed to first indication)				(Additional days elapsed to first indication)			
IRB	3	2	3	4	9	1	1	3	5
SRB	3	1	3	7	11	1	1	1	3
SLYM	1	1	1	0	2	1	1	1	3
Bacteria	2	4	4	5	13	-1	0	0	-1
Fungi	7	-1	-4	0	-5	-1	-1	-2	-4
	16	7	7	16		1	2	3	
EW-2D	**B1***	**B2**	**B3**	**B4**		**B5**	**B6**	**B7**	
		(Additional days elapsed to first indication)				(Additional days elapsed to first indication)			
IRB	4	0	0	1	1	0	0	2	2
SRB	4	2	0	3	5	1	1	2	4
SLYM	2	0	0	0	0	0	0	0	0
Bacteria	6	-2	-2	-4	-8	-4	0	0	-4
Fungi	6	0	0	-2	-2	0	-2	0	-2
	22	0	-2	-2		-3	-1	4	

Table II. Demand Study – BART & Dipslide Data Summary

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Conclusions

- PAA showed superior biocidal control in higher ORP in the shallow aquifer well.
- PAA's demand increased in the deep aquifer well due to lower ORP conditions
- Deposit control chemicals (DCC) retained mobile iron
- EDTA kept a substantial portion of iron mobile through greensand
- Other DCC's released >90% of iron to greensand

Additional Studies

- Bench Test
  - Fate of biocides and deposit control chemicals in unit operations
  - Greensand, Activated carbon
  - UVT of each reagent solution

Special Thanks

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