PRODUCED WATER SOCIETY
SEMINAR 2018

TECHNISCHE UNIVERSITÄT DRESDEN

Electrocoagulation in Produced Water

Operational Conditions and Forecasting Efficiency

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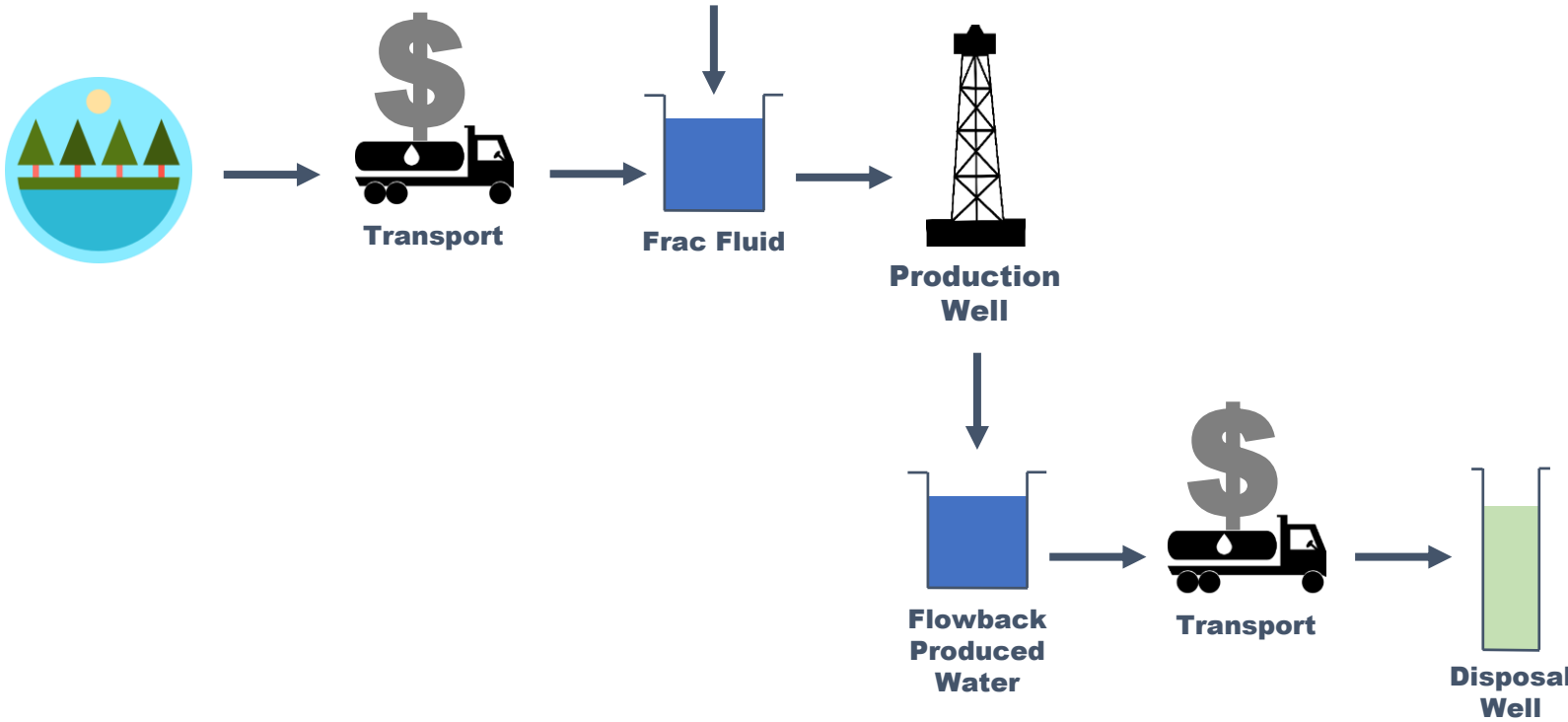
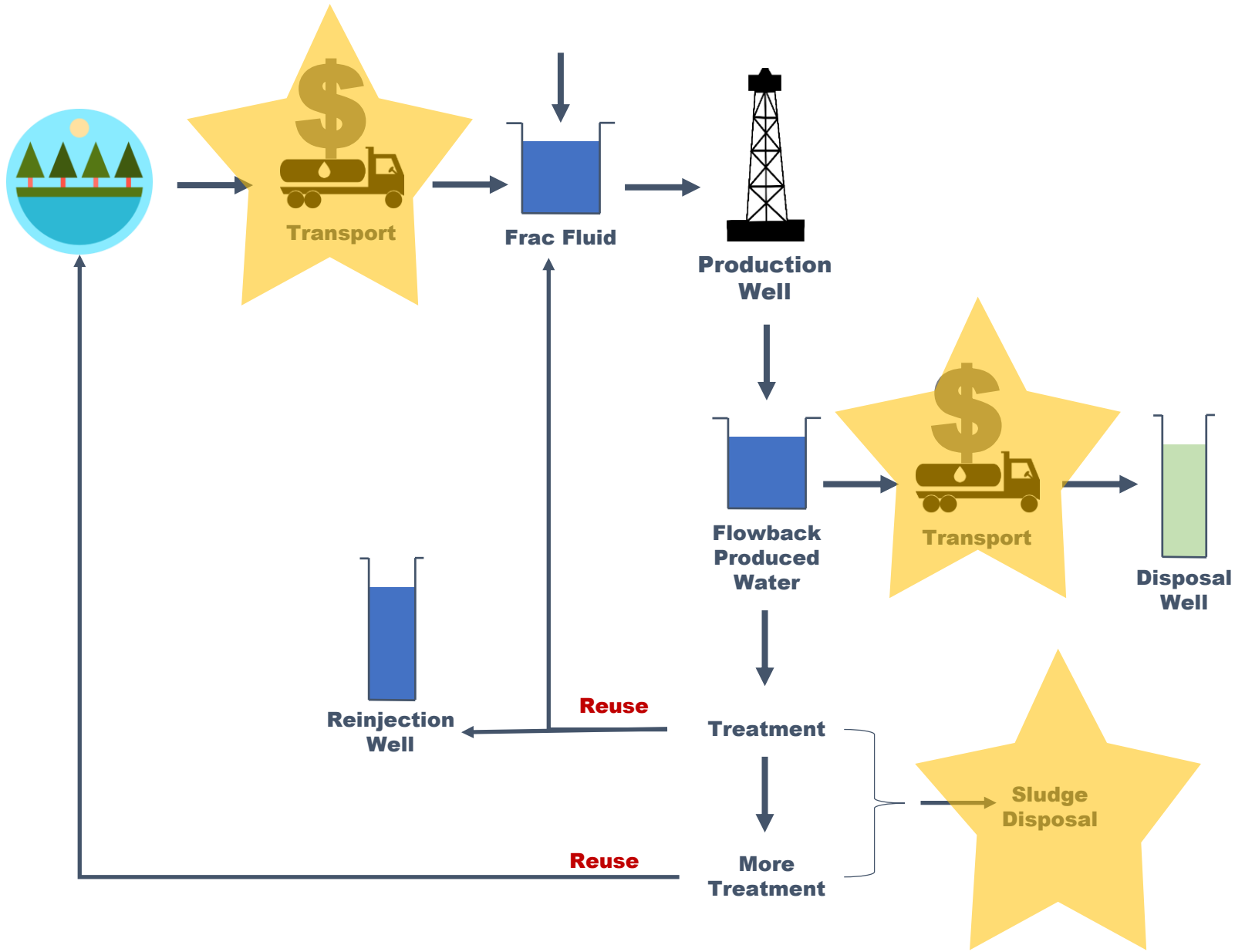
PhD Candidate

1. Realistic treatment for produced water
2. Electrocoagulation
3. Optimum operational conditions
4. Summary


Transport
Frac Fluid
Production Well
Flowback Produced Water
Transport
Disposal Well


Transport
Frac Fluid
Production Well
Flowback Produced Water
Transport
Disposal Well
Reinjection Well
Reuse
Treatment
Sludge Disposal
Reuse
More Treatment

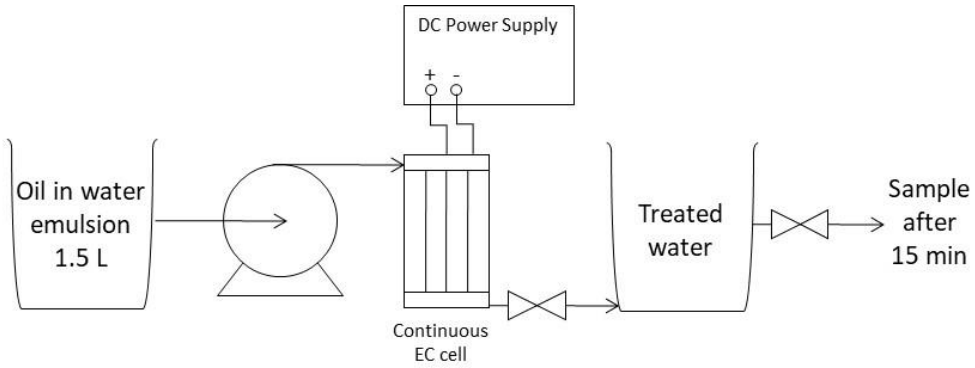
Realistic Treatment of Produced Water

⬆ Efficiency

⬇ Residence time

Realistic cost

Treating Produced Water



Parallel reactions

- Generation of Cl_2
- Oxidation/reduction reactions of some pollutants
- Precipitation of pollutants on the surface (carbonate/sulfate)

Buffer capacity

Treatment target

- Hydrocarbons
- Microorganisms
- Heavy metals
- Suspended solids
- Boron

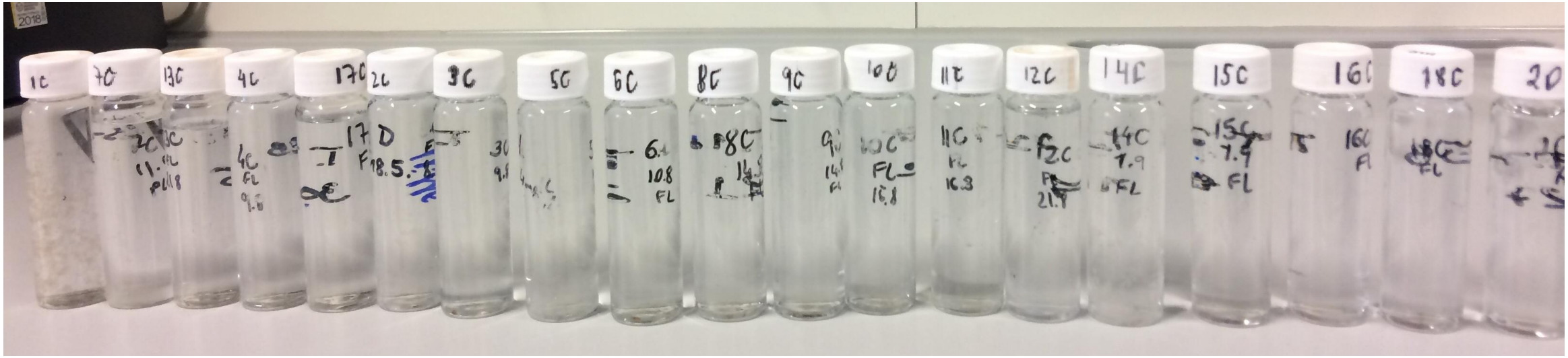
Less sludge

EC Capabilities

Reference	Target	Removal max [%]	Time [min]	Anode
Kamaraj et al, 2014	2,4-D	91,0	180	Fe
Gao et al, 2010	Algae	90,0	15	Al
Shuman et al, 2014	Algae	90,0	0,07	Ni
Parga et al, 2005	Arsenic	99,7	1,5	Fe
Sari and Chellam, 2015	Boron	49,0	~80	Al
Vakil et al, 2014	COD	99,9	20	Al
Hutnam et al, 2006	COD	91,0	15	Al-Fe
Ryan et al, 2008	COD	90,0	87	Fe
Cañizares et al, 2008	COD	73,3	10	al
Zhao et al, 2014	COD	65,0	30	Fe
Barrera-Díaz et al, 2011	COD	43	20	Fe
Hamdan and El-Naas, 2014	Cr	100	3	Fe
Manenti et al, 2014	DOC	44	60	Fe
Esmaeilirad et al, 2015	Hardness	60	0,6	Fe-Al
Vasudevan, 2014	phenol	98	30	Fe
Adhoum and Monser, 2004	polyphenol	91	25	Fe-Al
Karhu et al, 2012	TOC	~100	175	Al-Fe
Velero et al, 2011	TOC	80	5	Al

Low treatment time studies are not common

Optimizing EC Operational Conditions



How to achieve…?

- ⬇ Residence time
- ⬇ Energy ⬆ Efficiency
- Preset operational conditions

Response Surface Method

pH	Oil	Al-dosage
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1
-1.682	0	0
1.682	0	0
0	-1.682	0
0	1.682	0
0	0	-1.682
0	0	1.682
0	0	0
0	0	0
0	0	0
0	0	0

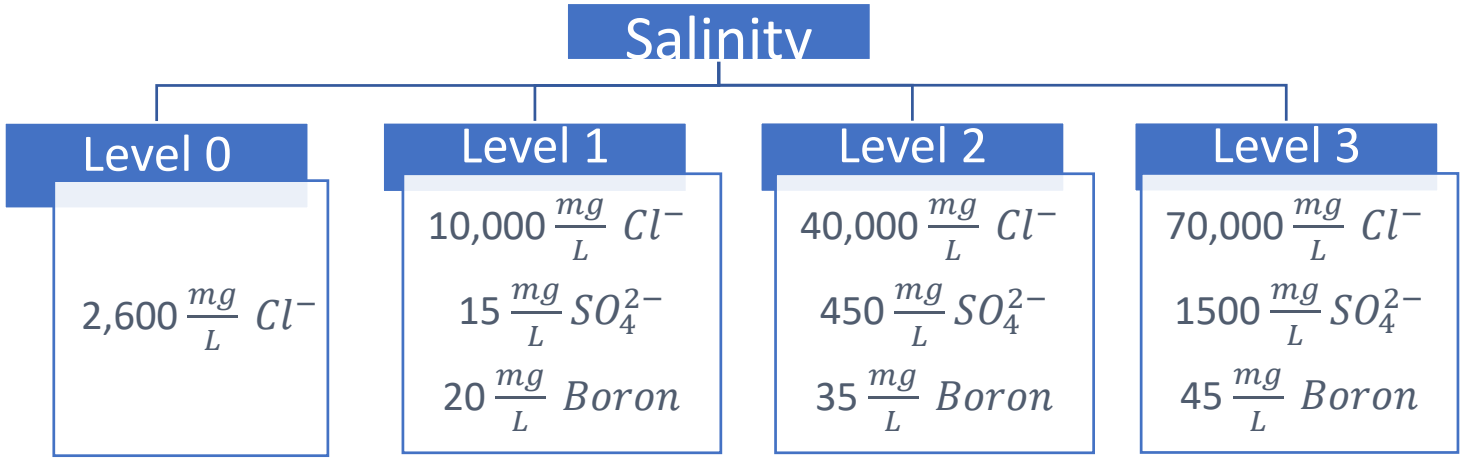
$$Y = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_{ii}^2 + \sum \beta_{ij} X_i X_j$$

$X_1 = Oil\ concentration$

$X_2 = Current$

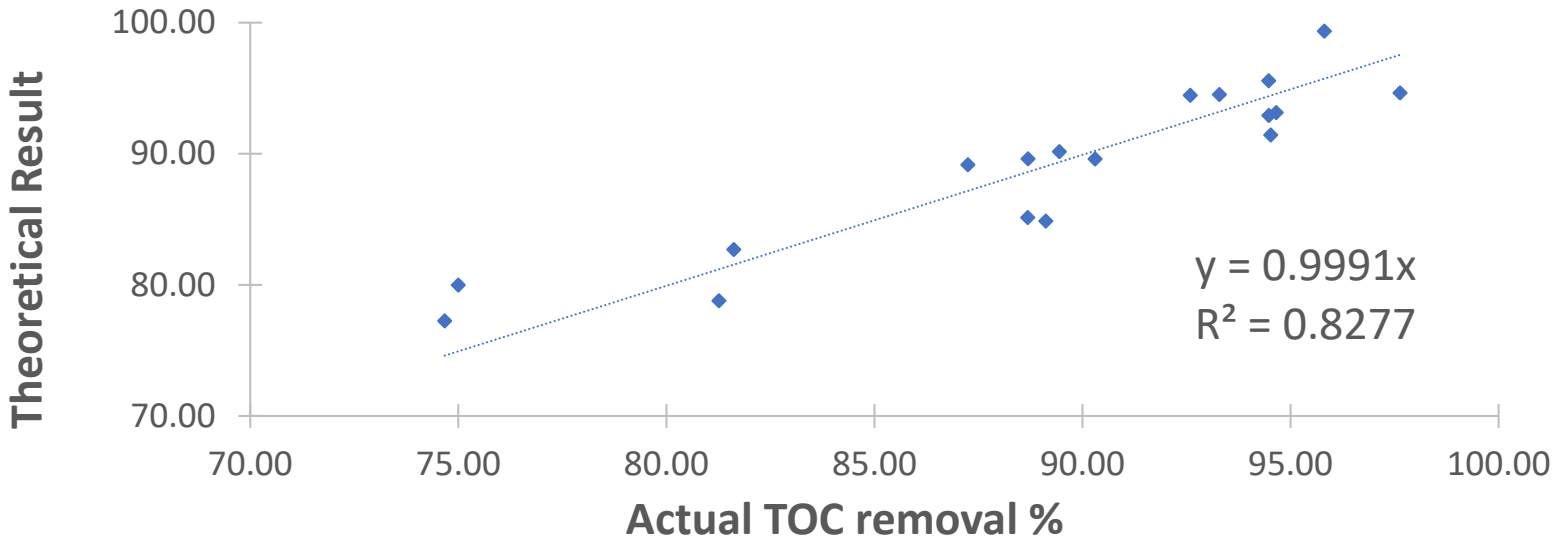
$X_3 = pH$

$Y_1 = TOC\ removal[\%]$



	pH	Oil [mg/L]	Al-dosage [mg/L]
-1.682	5.3	195	6
-1	6	400	19
0	7	700	38
1	8	1,000	57
1.682	8.7	1,204	70

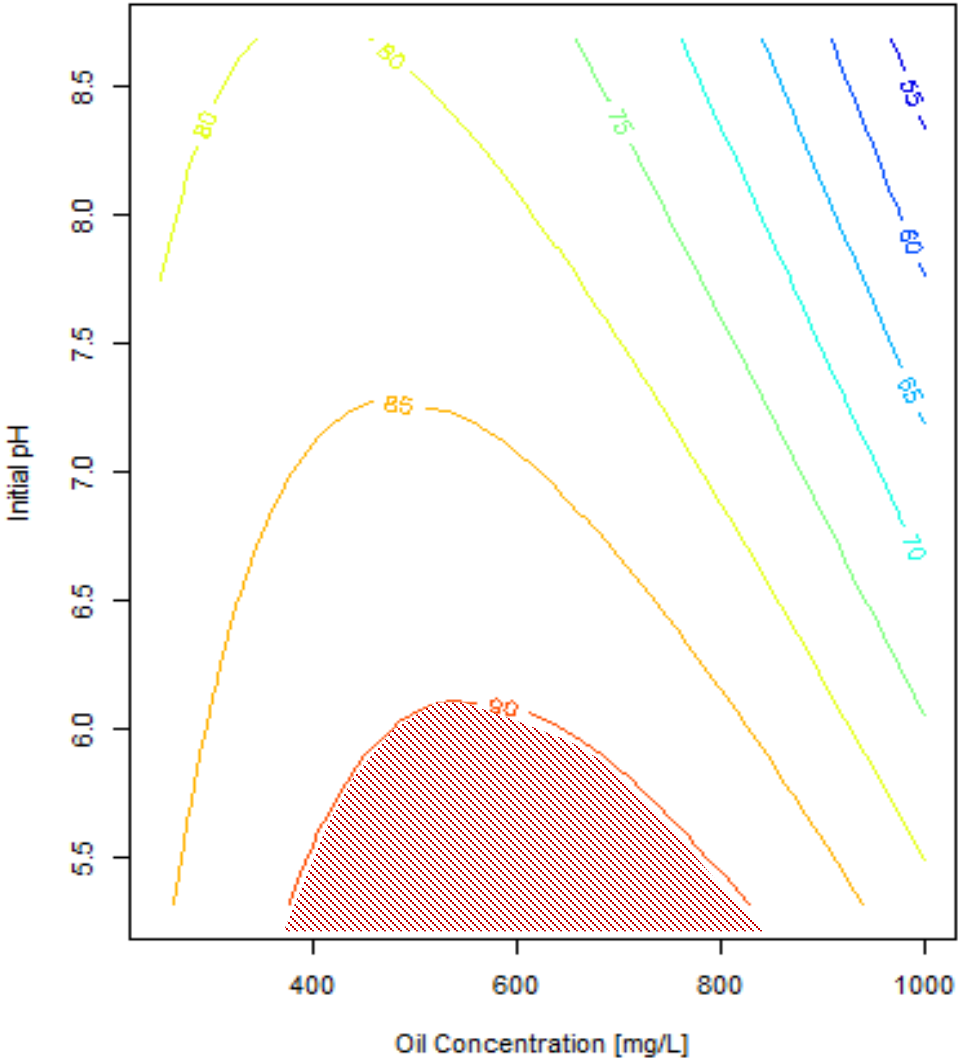
TOC Removal [%] Low Salt



- Buffer capacity of EC: pH initial from 5.5 to 8.6 → pH after EC was 8.2±0.3
- Sludge (V/V): 2.8%±1.2

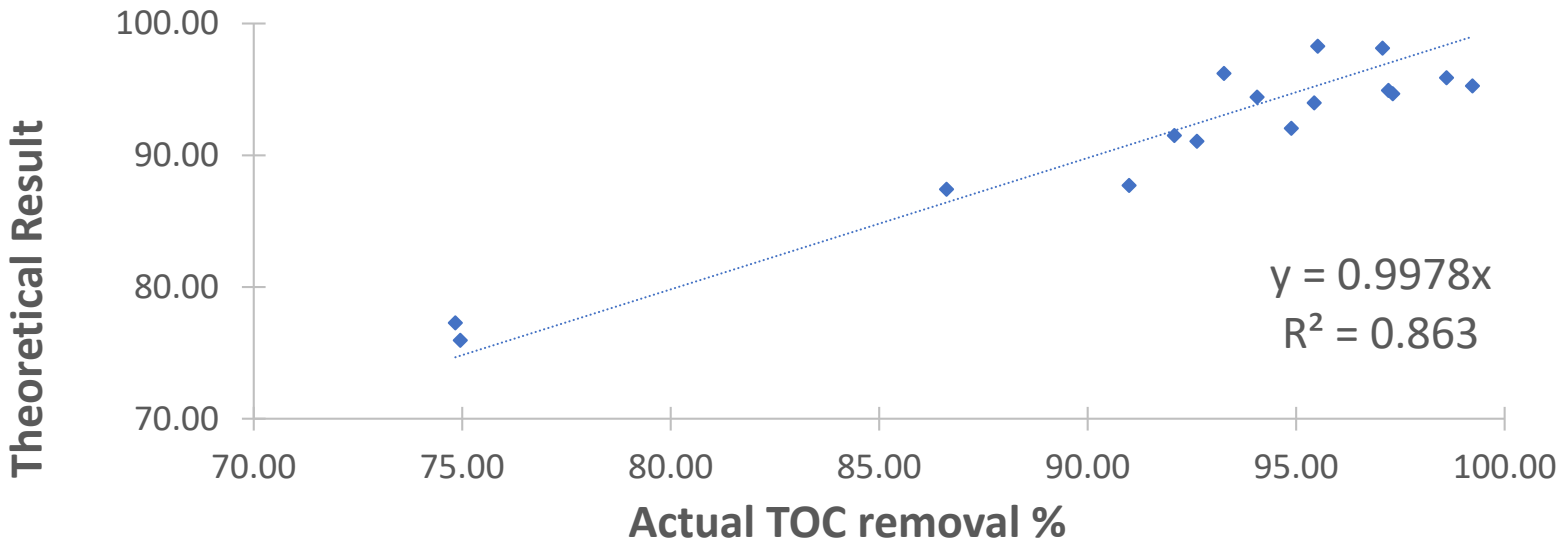
TOC Removal [%] Low Salt

Level -1 of Aluminum



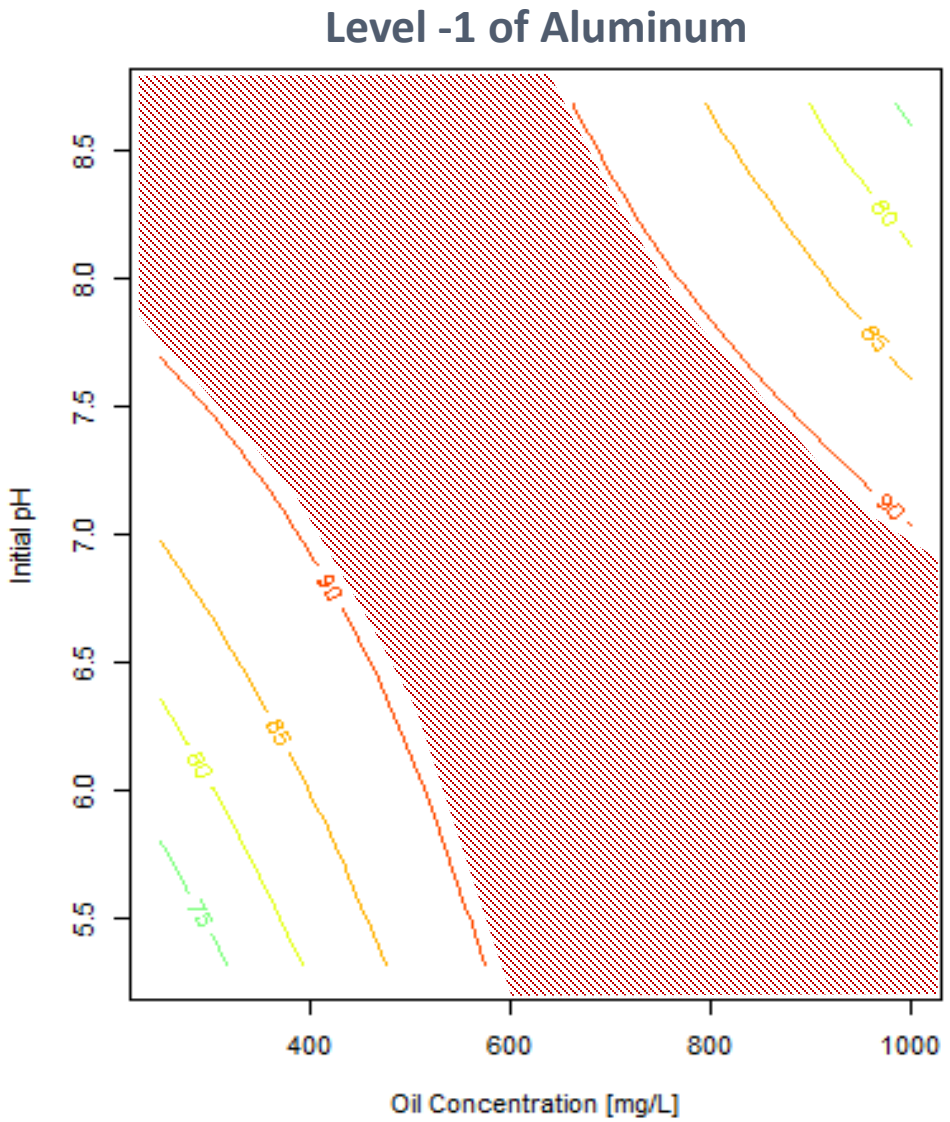
Level 1 of Aluminum

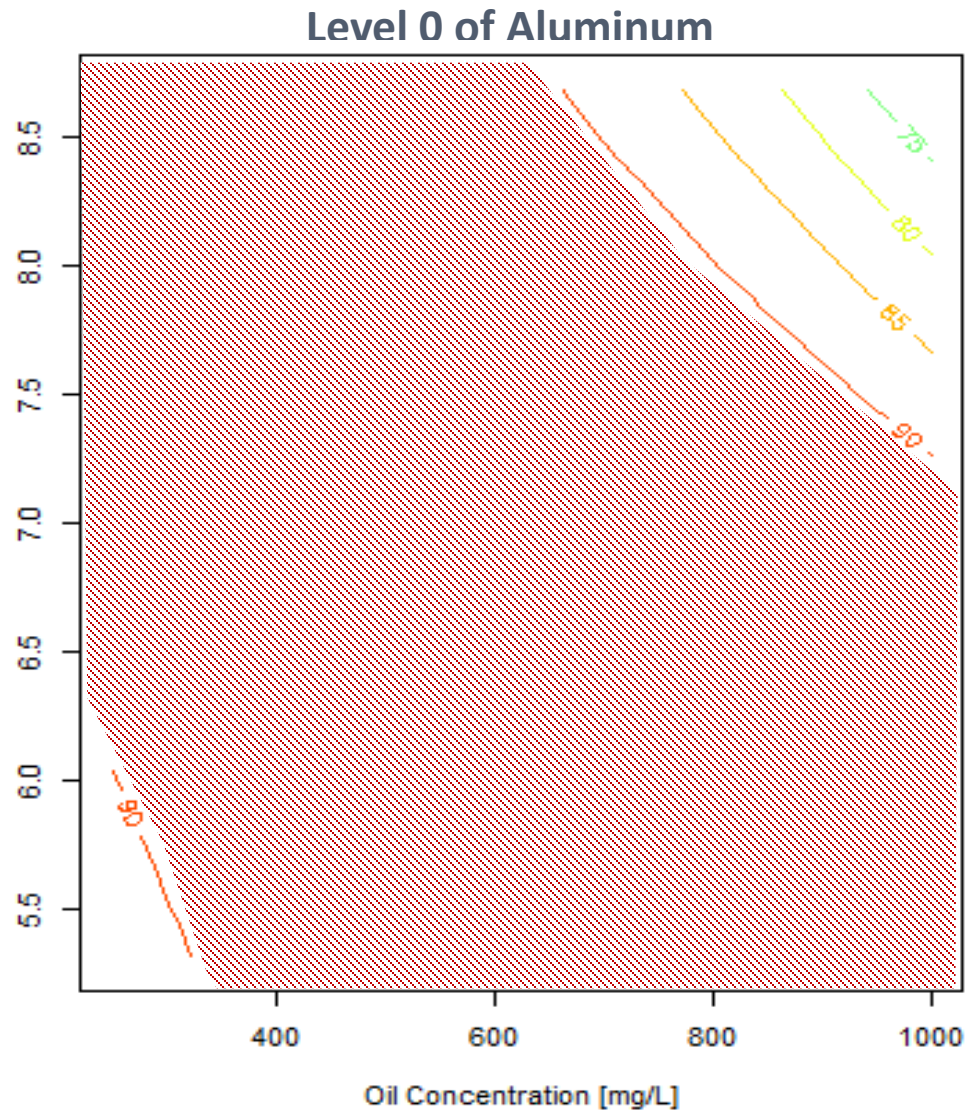
TOC Removal [%] Median Salt



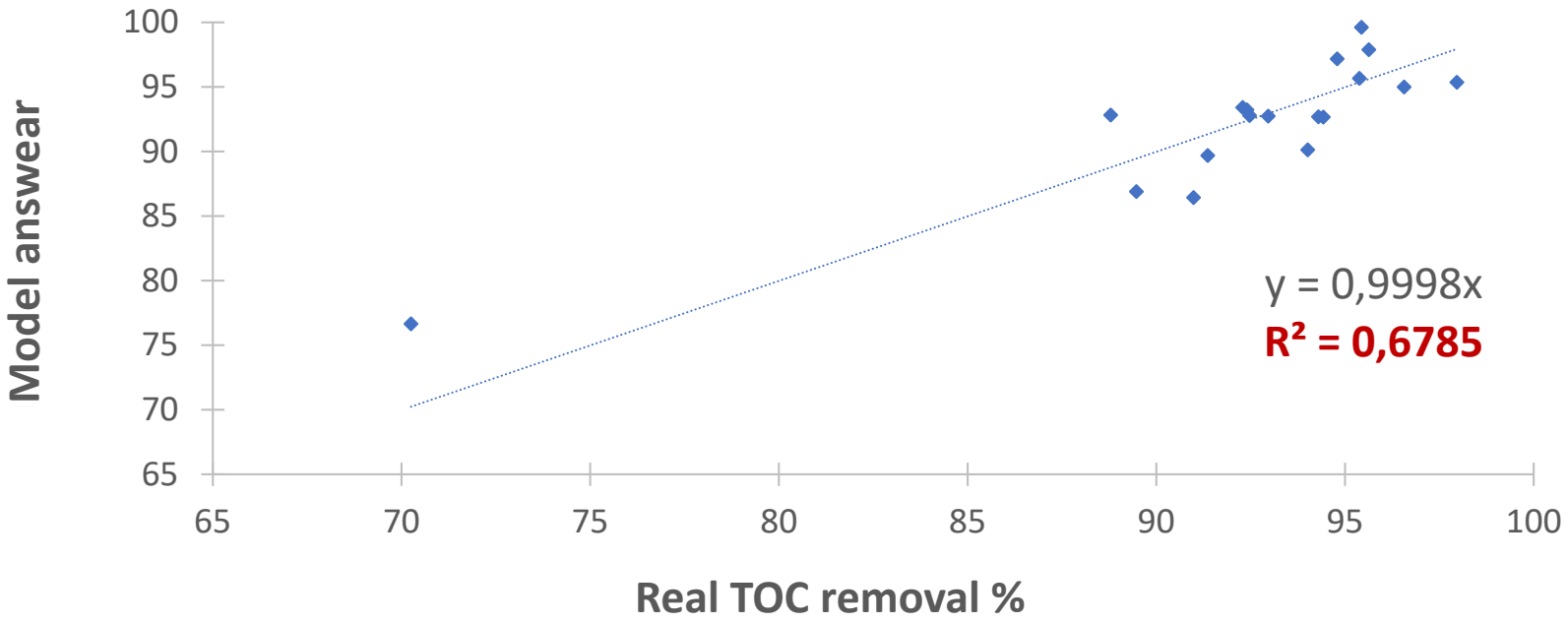
- Buffer capacity of EC: pH initial from 5.4 to 8.7 → pH after EC was 8.0±0.3
- Sludge (V/V): 3.0%±1.0

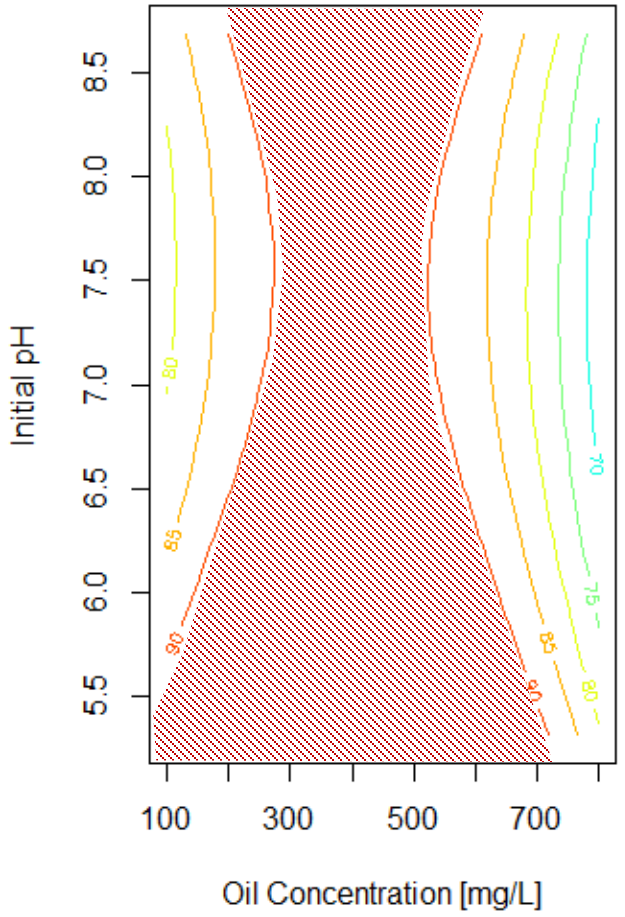
TOC Removal [%] Median Salt





TOC Removal [%] High Salt

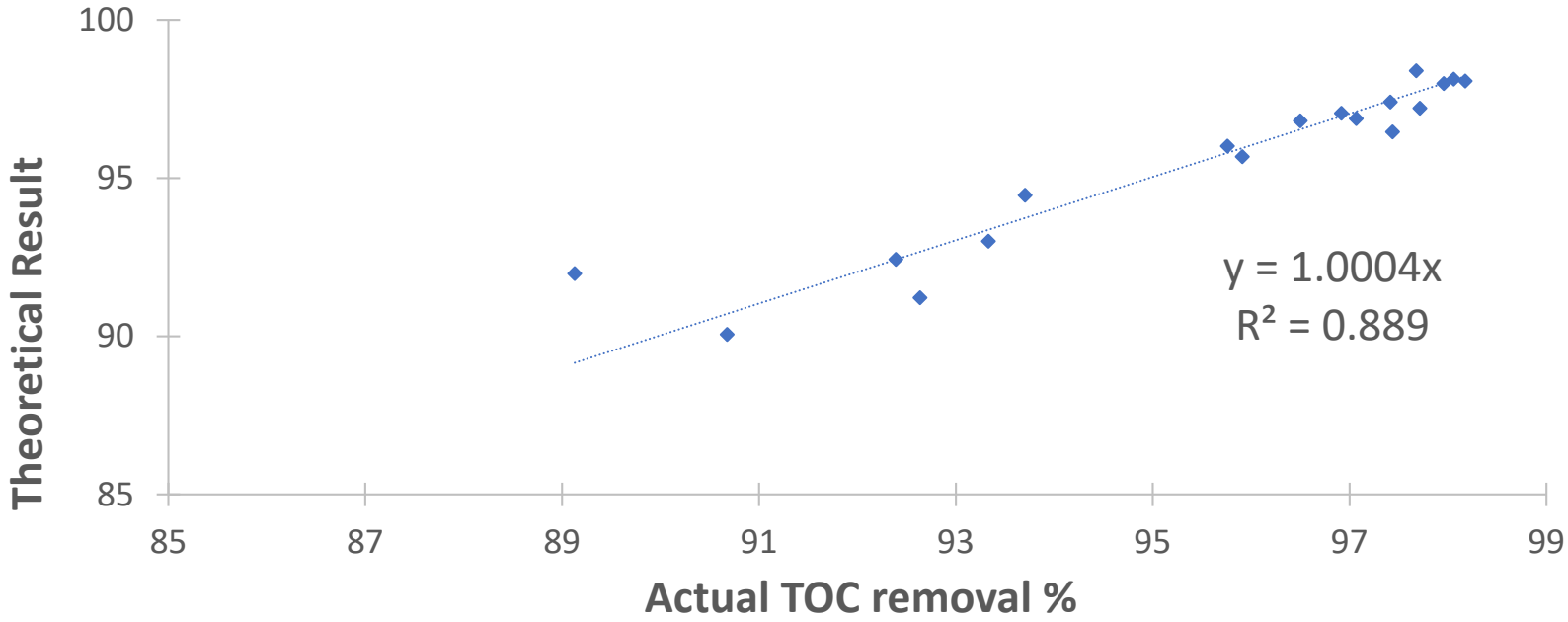




Level -1 of Aluminum

- Buffer capacity of EC: pH initial from 5.8 to 8.7 → pH after EC was 8.1±0.3
- Sludge (V/V): 3.0%±1.0
- TOC analysis with high salinity

TOC Removal [%] Very Low Salt



- Buffer capacity of EC: pH initial from 5.3 to 8.7 → pH after EC was 7.0±0.8
- Sludge (V/V): 1.3%±0.4
- **All results were high removal in all coagulante dosage**

Optimization of Electrocoagulation in Produced Water

- De-oiling efficiency ≥ 90%
- Residence Time ≈ 4 seconds
- Cost
  - →0.03 USD/bbl
  - →0.13 USD/bbl (with sludge disposal)

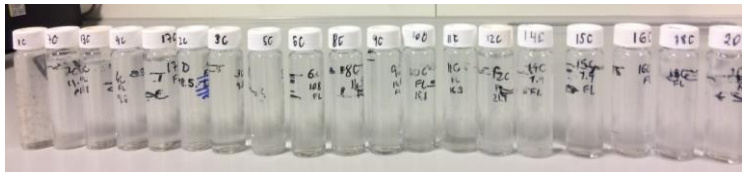
Next step- Real produced water test

* 0.1 USD per Kwh

3 USD per Kg coagulant

15 USD per m^3 of sludge

Summary

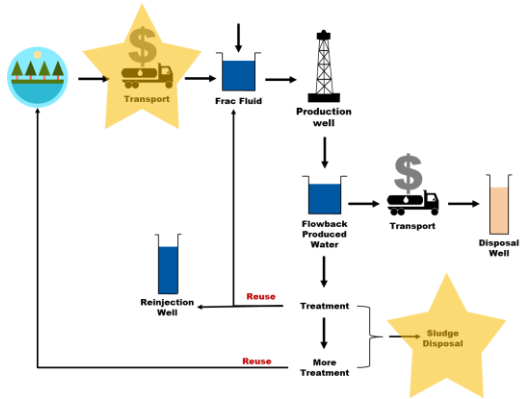


Optimum on the op. conditions

- ↑Removal with ↓ Energy Demand
- Operation conditions preset for pilot tests or real treatment

Electrocoagulation

- High Removal Efficieny
- ↓Sludge & chemicals
- ↓Transportation cost
- ↑ Safety
- Removal of Boron



Realistic Treatment for Produced water

- ↓ Residence time
- Realistic cost
- ↑ High de-oiling → tech-economical viable postreatment for reuse

Thank you

Questions?

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P-value TOC Removal %

35% of Boron removal in one experiment (level 1.682)

Salinity	F value (9 on 8 DF)	P-value
Very Low	8.015	0.3%
Low	5.157	1.5%
Median	6.037	0.9%
High	2.769	8.3%

- Bicarbonate influence

Salinity	TOC removal [%]	Model TOC removal [%]
Low	90.63	87.11
Low	93.58	90.44
Median	91.61	91.58
Median	90.27	91.88

- Flow of EC cell≈0.4 bbl/h
- Temperature ≈ 22 °C / 72°F

Parameter (mg/l)	Produced Water Range	Produced Water Range	Range for Brazilian Produced Water	Mean of Brazilian Produced Water
Density (kg/m³)		1014-1140	1030-1130	1050
Condutivity (µS/cm)		4,200- 586,000		
Surfate tension (N/m)		0.043-0.078		
Temperature °C	20- 150		30-90	59
pH	4-10	4.3-10	6.06-8.2	6.98
Oil-in-water	5- 1,000	2-565		
Total organic compounds (TOC)		0-38,000	86-971	307
Total Suspended Solids (TSS)	1- 500	8-5,484	1.9-106.1	10.6
Total Dissolved Solids (TDS)	10,000-336,000	2,600-360,000	38,182-179,766 (as NaCl)	75,434 (as NaCl)
BTEX	0-100		1.40-19.99	4.87
Chloride	6,000-200,000	80-200,000	23,170-109,089	45,776
Bicarbonate	100-6,000	77-3,990	115-730	436
Carbonate	0- 1,000			
Sulfate	0-5,000	ND-1,650	17-2,243	481
Ammonia	10-200	10-300	22.3-91	51.7
Total polar		9.7-600		
Higher acids		<1-63		
Phenol		0.009-23		
Volatile fatty acids		2-4,900		
Acetate	0- 2,500		45-783	365
Propionate	0-400		ND-200	47
Butyrate	0-75			
Dissolved Oxygen	0			
Dissolved H_2S	0- 1,000			
Bacteria (total) per ml	$0\text{-}10^{10}$			
Aluminum		<0.5-410	<0.003-0.32	0.1
Barium	0-20,000	1.3-1,740	0.4-45	2
Boron		ND-95	18.4-120.4	36.4
Cadmium		<0.005-1.2	<0.001-0.2	<0.02
Calcium	0- 40,000	13-51,300		
Chromium		0.02-1.1	<0.005-0.03	<0.005
Copper		<0.02-5	0.01-0.29	0.12
Iron	0- 200	<0.1-1,100	0.04-17	1.1
Lithium		3-235		
Lead		0.002-10.2	<0.001-0.1	<0.1
Magnesium	0- 4,000	0.9-6,000		
Manganese		<0.004-175	0.04-5.89	0.35
Potassium	0-1,000	24-4,300		
Strontium	0- 10,000	0 -6,200		
Sodium		132-120,000		
Titanium		<0.01-0.7		
Zinc		0.01-35	<0.2-0.05	<0.2
Arsenic		<0.005-151	<0.007-0.2	<0.2
Mercury		<0.001-0.002	<0.2-0.63	<0.2
Silver		<0.001-7	<0.001-0.003	<0.003
Beryllium		<0.001-0.004