Electrocoagulation Utility in the Mining and Oil & Gas Industry

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Agenda

- Introduce Halliburton Energy Services & Baroid IDP
- What is Electrocoagulation
- Optimization Techniques
- Case Histories

HALLIBURTON

- Secured a global licensing agreement with Water Tectonics in April of 2010.
- Technology used in treating wastewater from mining and Oil & Gas activities.

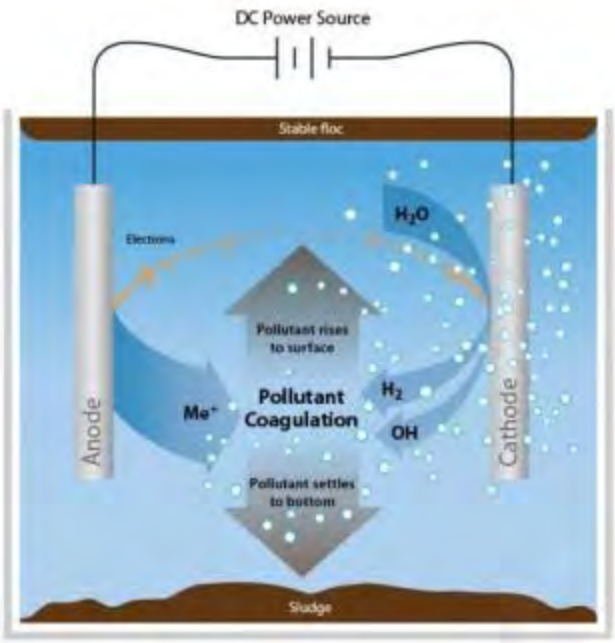
Our Technology

What is Electrocoagulation?

- **Electrocoagulation** - process utilizing “sacrificed” anodes to form active coagulants which are used to remove pollutants by precipitation in-situ.
- *“Compared with traditional chemical coagulation, electrocoagulation has, in theory, the advantage of removing the smallest colloidal particles; the smallest charged particles have a greater probability of being coagulated because of the electric field that sets them in motion.” - MF Pouet, 1995*

Electrocoagulation Process

- Electrocoagulation (EC) removes contaminants from an aqueous solution by use of two electrodes.
- The electrical process introduces positively charged ions that are capable of attracting a disproportionate quantity of negatively charged contaminants.
- Result of reaction is an agglomeration of small particles to larger particles.
- Gas generated at the cathode assists in separating the flocculated particles.



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EC Chemistry: Iron

Anode Reaction

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$$

Iron Oxidation Reaction

$$Fe^{2+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + 1e^-$$

Iron Hydroxide Coagulant

$$Fe^{3+}_{(aq)} + 3OH^-_{(aq)} \rightarrow Fe(OH)_{3\ (s)}$$

Iron Hydroxide Precipitant

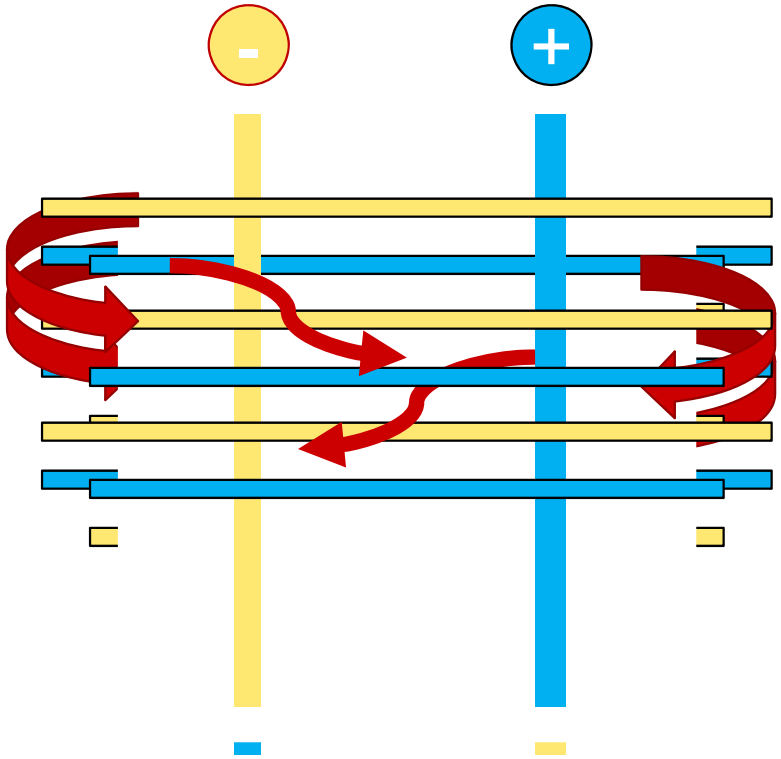
$$Fe^{3+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_2^-{}_{(aq)}$$

The iron released during the electrocoagulation process is more active since it is not tied up ionically with sulfate, chloride or other anions when added to the solution.

EC Cell Architecture

- The cells architecture provides the maximum amount of contact surface area and a tortuous path for the fluid to ensure mixing of the coagulants.

- The tortuous path of the flow and alternating the anode and cathode help keep the cell “clean” and prolong the cell life.



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Technology and the Contaminants

Typical EC Target Contaminants

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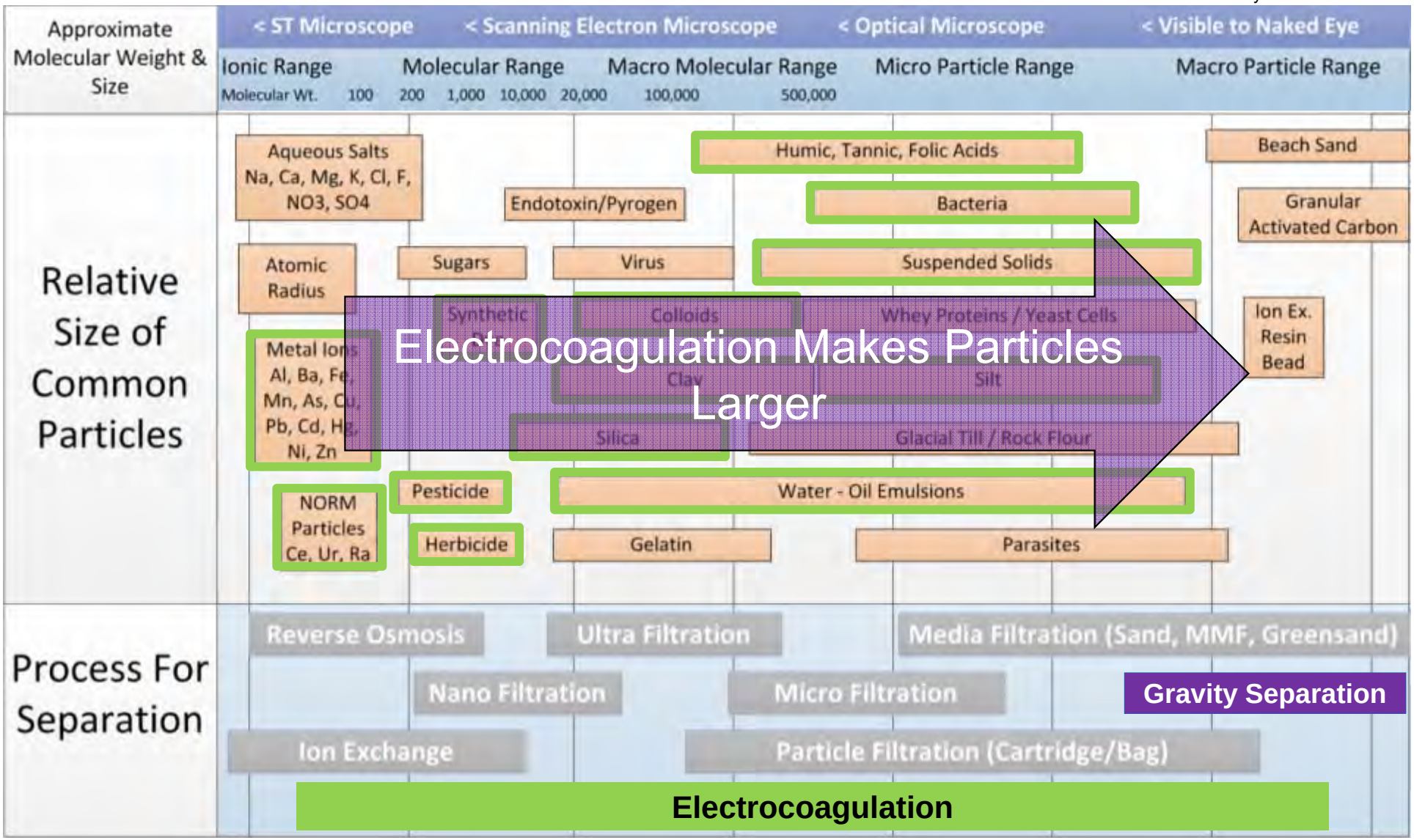


Today's Treatment Technologies

Ultra Filtration

Electrocoagulation

COMPLEX

Reverse

Mechanical

Ozon

Ion

Advantages of EC

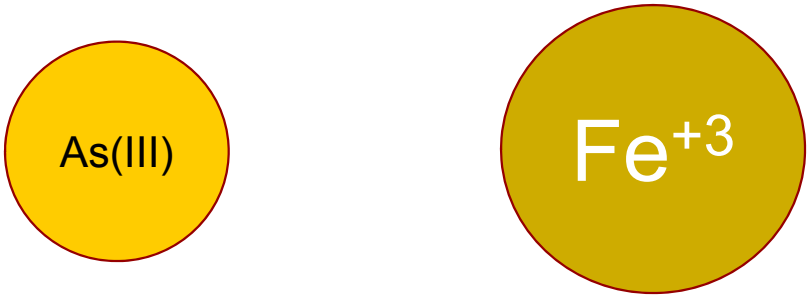
- High energy reaction creates collisions and forms particles through precipitation and adsorption.
- Does NOT add aqueous salts to the treated solution. No addition to osmotic loading on downstream processes.
- Ionically driven reaction, that, unlike a stoichiometric reaction, consumes 100% of the cation flocculent.
- Produces less sludge when compared to traditional chemical precipitation.

Analyte	CleanWave® Removal Efficiency**				
	Excellent	Good	Fair	Marginal	Inert
	>95%	70 - 95%	25 -70%	10 - 25%	<10%
Alkalinity					
Aluminum					
Antimony					
Arsenic					
Barium					
Calcium					
Cadmium					
Chloride					
Chromium					
Fluoride					
Iron					
Lead					
Magnesium					
Manganese					
Mercury					
Molybdenum					
Nickel					
Nitrate					
Nitrite					
pH					
Potassium					
Selenium					
Silver					
Silica					
Sodium					
Strontium					
Sulfate					
Suspended Solids					
Total Dissolved Solids					
Turbidity					
Uranium					
**pH adjustment and solids separation dependent					

Typical Treatment Train with CleanWave® EC

- Redox Optimization
  - *In-Situ* dissolved oxygen control, if needed
- CleanWave Electrocoagulation Flocculation
- pH adjustment, if needed
- Compatible with Solids Separation and Media Filtration
  - Passive settling or mechanical separation
  - Mineral Media, UF and NF

Arsenic (III)

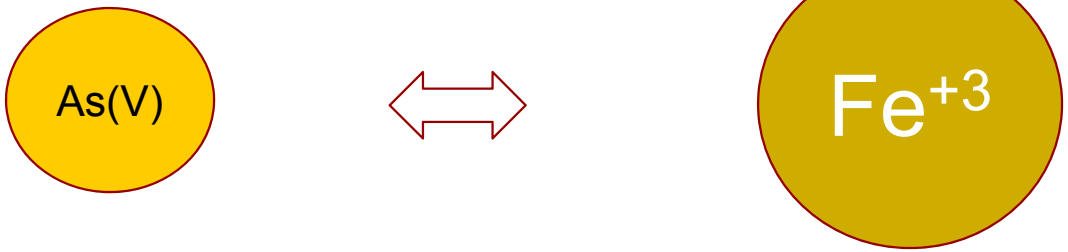


No Attraction

Oxidation

Creates negatively charged As(V)

Arsenic (V)



Attracted and bound to Ferric precipitate

Case Study – Tailing Storage Drainage Reuse

Location	Legacy Gold Mine
Application	Tailing Storage Facility (TSF) Drainage
Equipment	EC / MMF / RO
Discharge	Reuse / Discharge
Volume	50 gpm
Effluent Goal	As, Ca, Mg, Fe, Mn, SO_4, TDS, TSS

Case Study – Tailing Storage Drainage Reuse

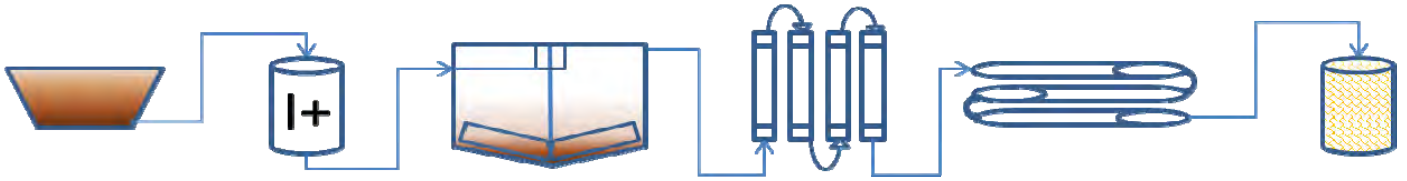
Parameter	Units	Influent	EC Effluent		RO Permeate		Treatment Objective
Arsenic	mg/l	7.48	0.01	99.9%	<0.003		<0.005
Calcium	mg/l	689	674		4.0	99.9%	
Magnesium	mg/l				<1	99.9%	
Iron	mg/l	375	0.22	99.9%	0.05		<1.0
Manganese	mg/l	11.7	0.06	99.5%	0.005		
Nickel	mg/l	1.160	0.080	93.1%	<0.010		<0.020
Sulfate	mg/l	4,580	4,630		34	99.9%	<200
TSS	mg/l	105	10	90.5%	1		<5.0
TDS	mg/l	12,100	11,900		255	99.9%	<1,000

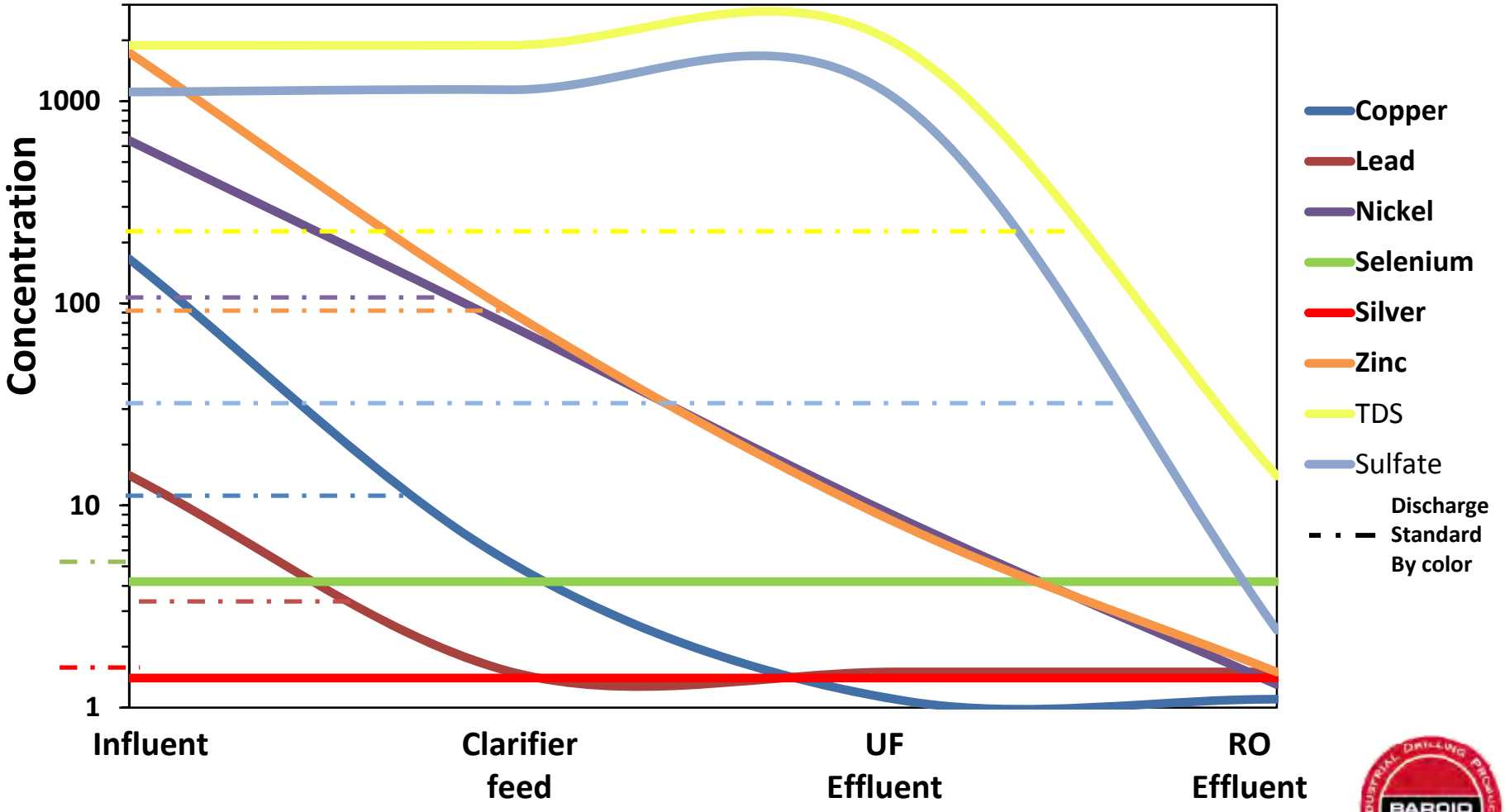
Required for RO Operation

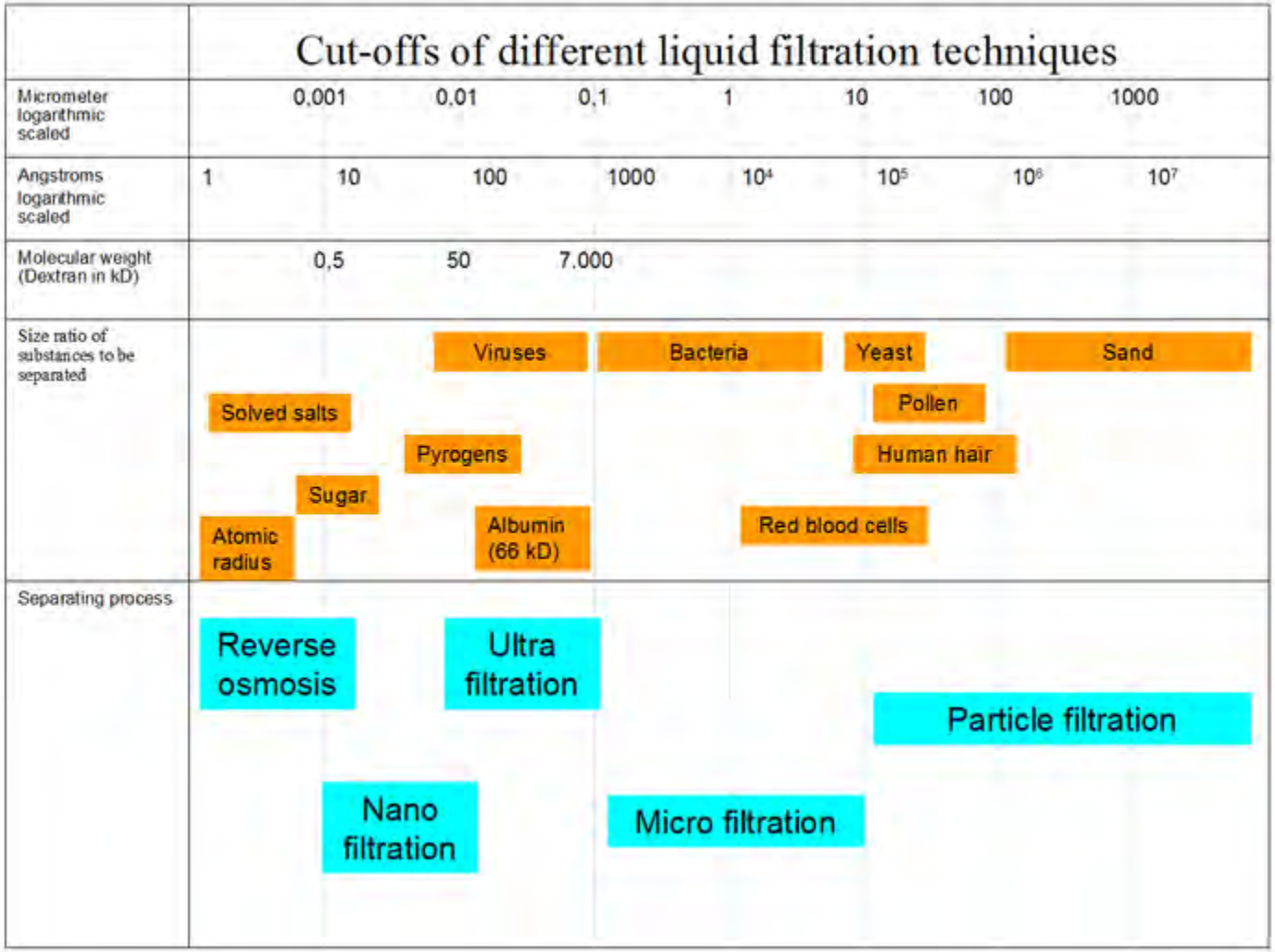
Case Study – Closed Mine/Open Pit

Location	Legacy Barite Mine
Application	Closed Open Pit Mine Lake/Drainage
Equipment	EC / Clarifier / UF/ RO (and NF)
Discharge	Discharge
Volume	550 gpm
Effluent Goal	Cu, Pb, Ni, Zn, Ag, Se, SO_4, TDS

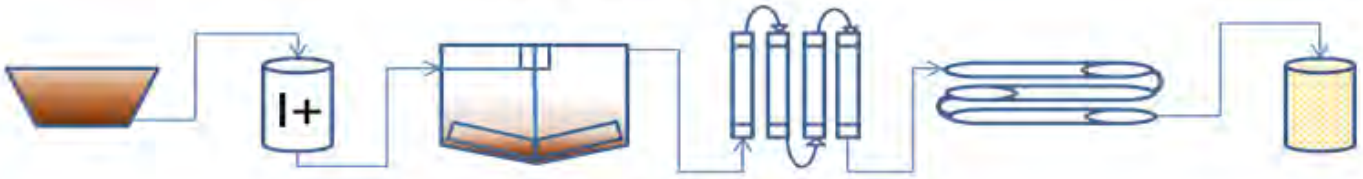
CleanWave Unit

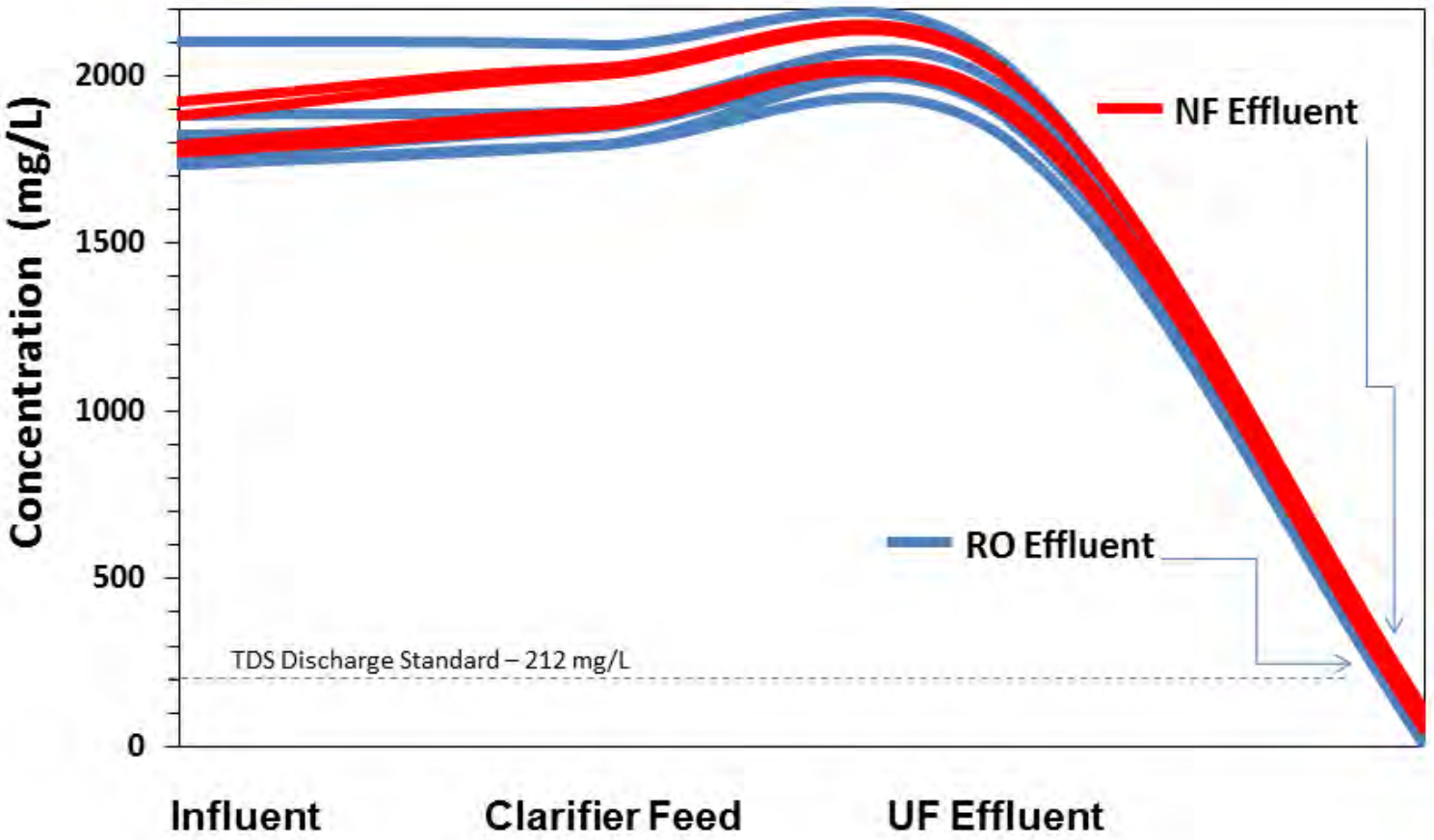




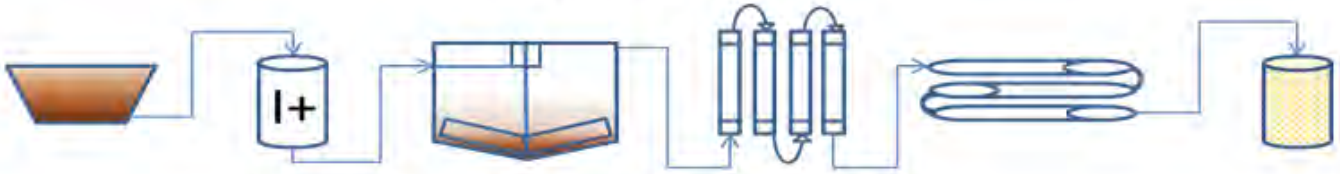


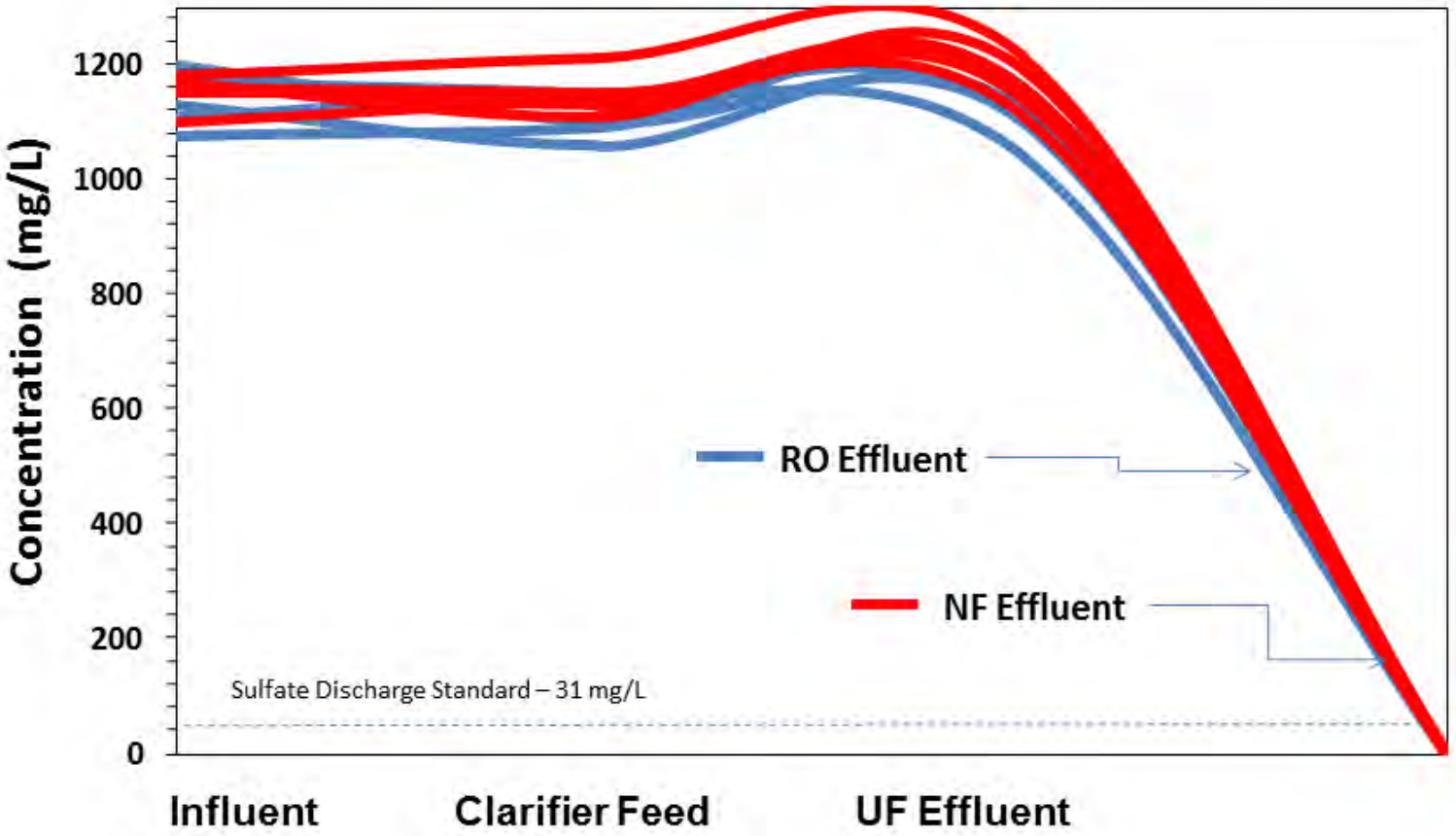
TDS Removal Efficiency
NF vs RO





Sulfate Removal Efficiency
NF vs RO



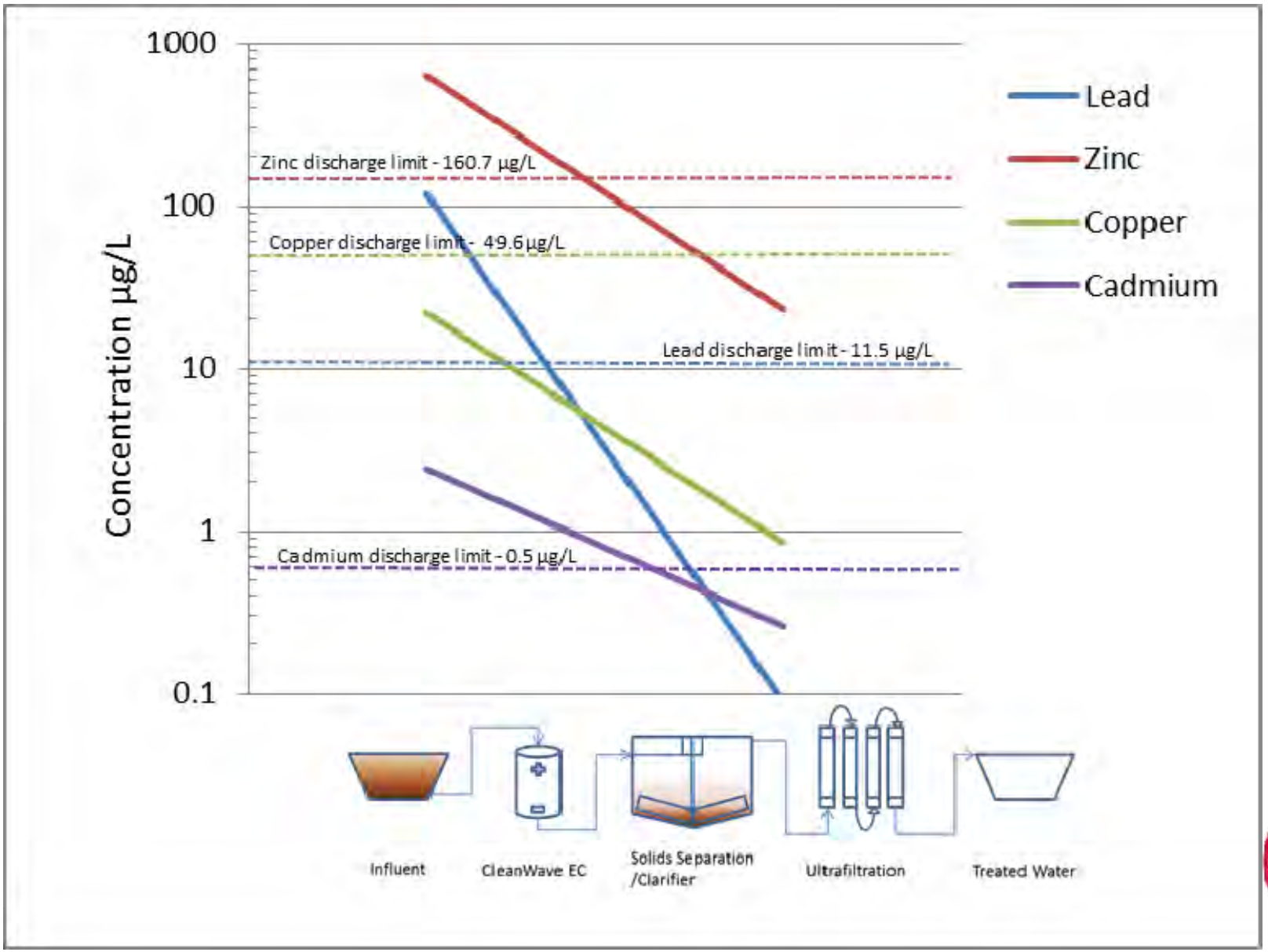


Case Study – Producing Lead Mine

Location	Missouri
Application	Pb, Zn, Cu, and Cd removal
Equipment	EC / UF
Discharge	Surface stream
Volume	300 gpm
Effluent Goal	Pb – 11.5 µg/L Zn – 160.7 µg/L Cu – 49.6 µg/L Cd – 0.5 µg/L

Electricity usage – Average **$25.33/day-** includes 300 GPM CleanWave EC, Ultrafiltration, and all transfer pumps between equipment

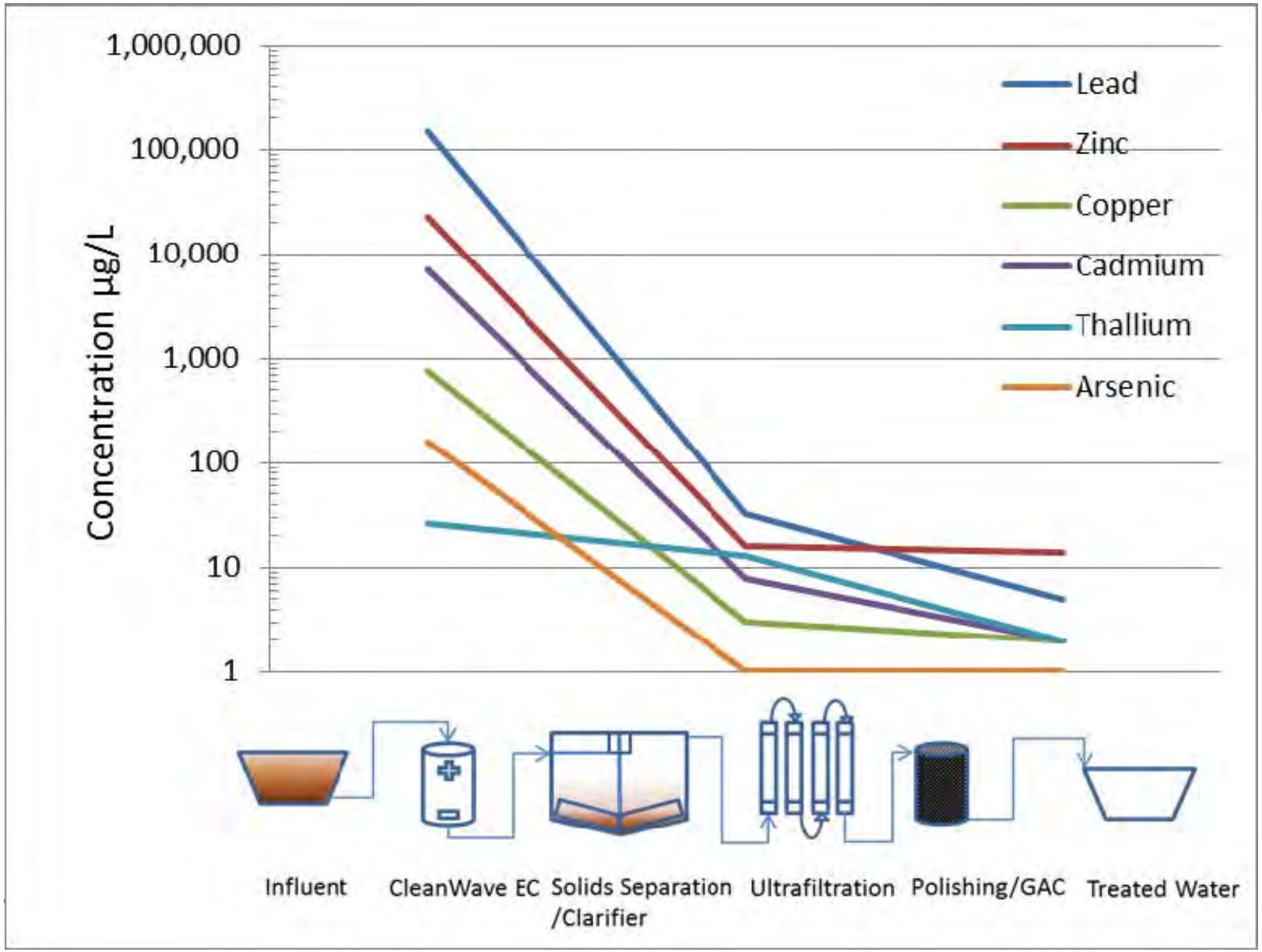
Heavy Metal removal at Operating Lead Mine



Case Study – Former Lead Smelter

Location	Missouri
Application	Pb, Zn, Cu, CD, As, Tl, and Sb removal
Equipment	EC / UF / GAC
Discharge	River
Volume	100 gpm
Effluent Goal	Pb – 1.26 lb/day Zn – 3.73 lb/day Cu – 1.4 lb/day Cd – 0.61 lb/day As – 1.69 lb/day Tl – report only Sb – report only

Heavy Metal Removal from Lead Smelter



Case Study – Producing Gold Mine

Location	U/G Nevada
Application	TSS removal
Equipment	Centrifuge / EC / UF
Discharge	Reuse in U/G
Volume	75 gpm
Effluent Goal	TSS <50 NTU post EC,

	TSS (mg/L)		
Date	Influent	Post CleanWave®	Post UF
12-15-14	80	36	9.3
12-18-14	19,900	147	7.2
12-19-14	2,400	63	10.7

- Other considerations:
  - Permitting if water goes to surface
  - Improve water quality to surface WTP (MF/RO)
  - Ore recovery from dewatered slimes

Centrifuge Underground

Centrifuge separating solids

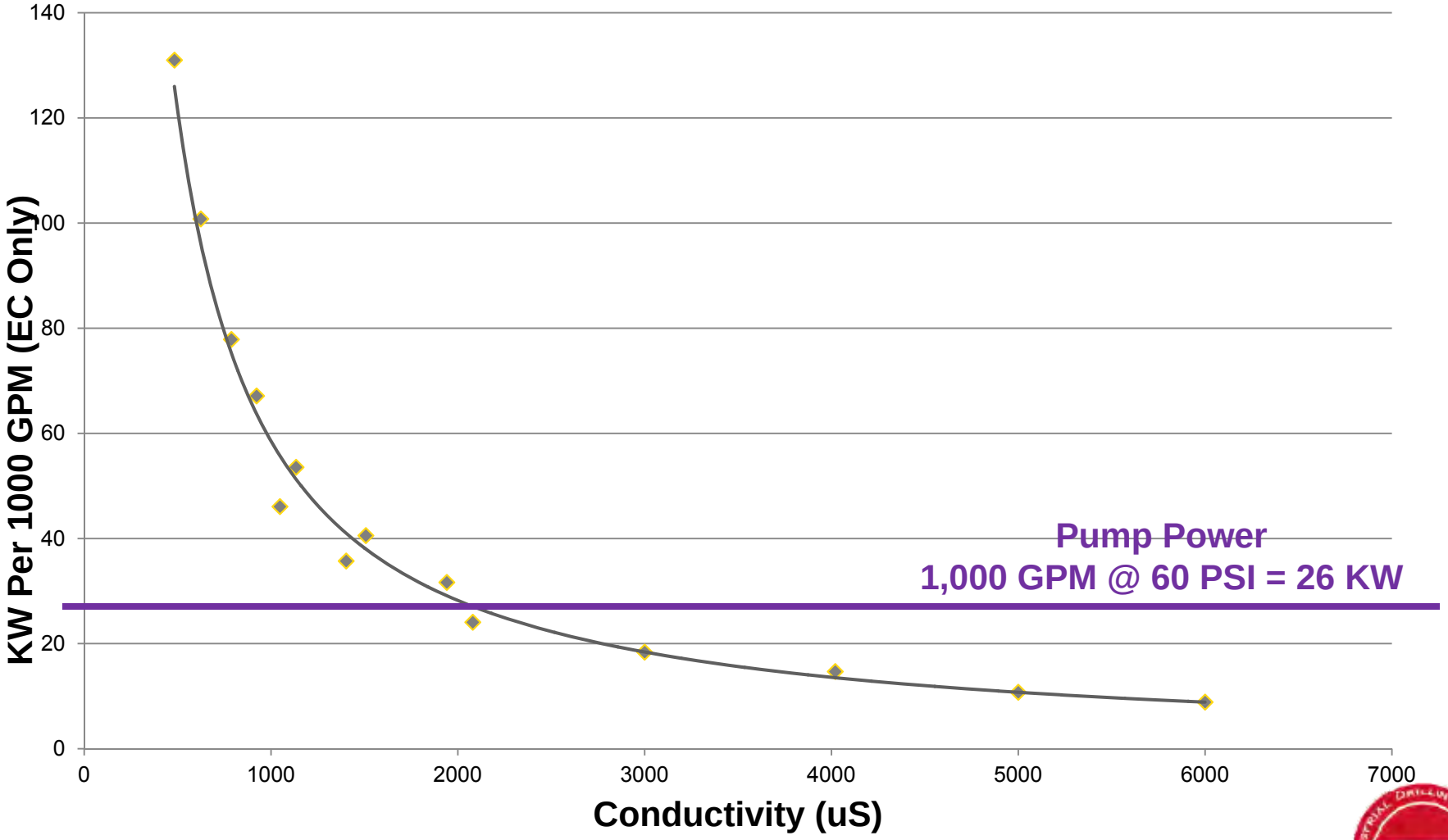
EC Underground

Treatment Opportunities with CleanWave® EC

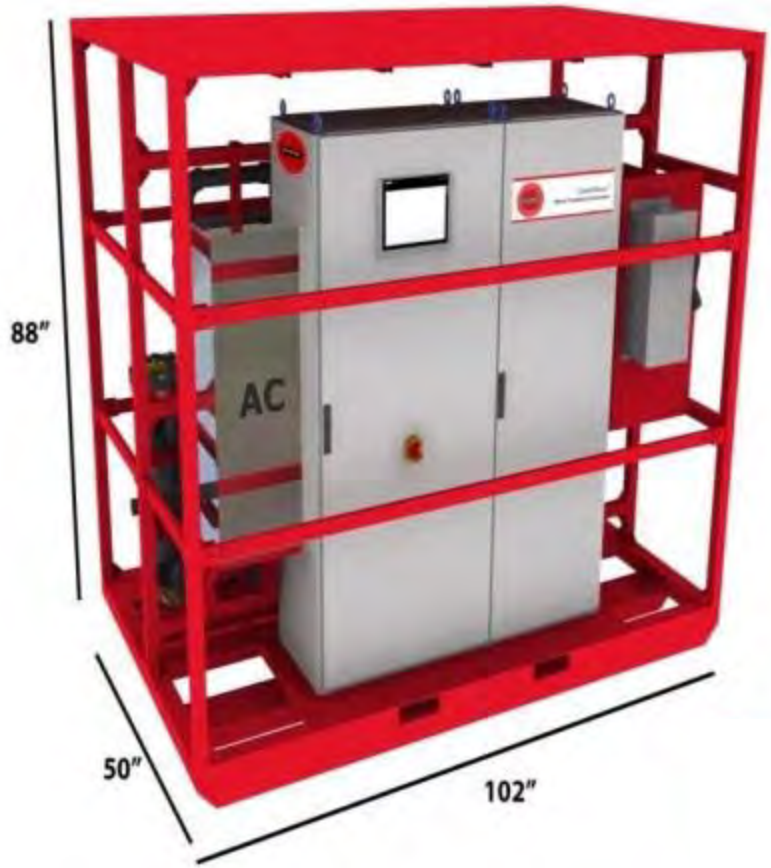
- U/G
  - Clarification (turbidity) for reuse U/G
  - Permitting friendly pre-treatment for membrane processing
- Mobil metals and solids pre-treatment
  - Closure
  - Dewatering
  - AMD applications
- Pretreatment for existing membrane
- Incorporating EC into comprehensive treatment strategy

Electrocoagulation Power Usage

Provided by WaterTectonics



CleanWave® EC Pre-treatment Equipment: Automated, Scalable and Mobile



Lab Bench Testing and Field Confirmation

- Lab-based solutions
- Commissioning report
  - Water performance targets
  - Solids characterization
  - OPEX estimates
- Process design
- Rental vs. CAPEX/OPEX


THANK YOU