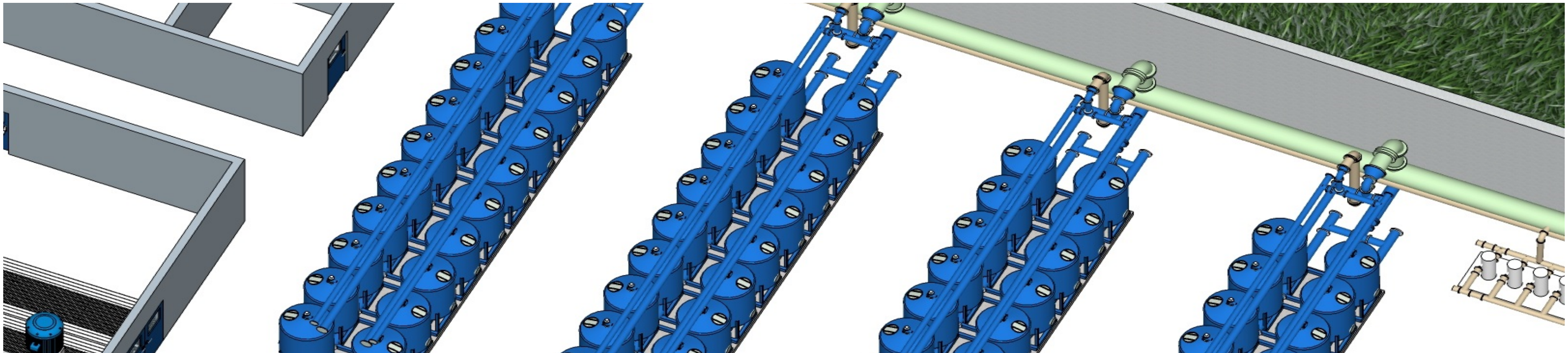


Groundwater Treatment Technology

Lee Odell/Global Technology Lead for Groundwater Treatment

April 2019

JACOBS®

www.jacobs.com | worldwide

Key Groundwater Treatment Issues

Iron and Manganese

Nitrate

Ammonia

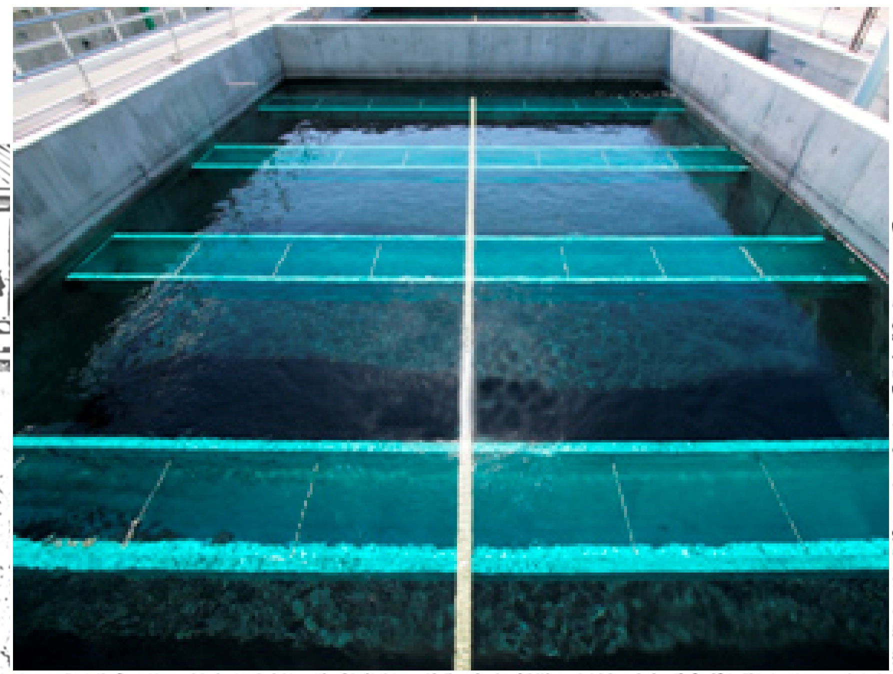
PFOS and PFOA

Hexavalent Chromium

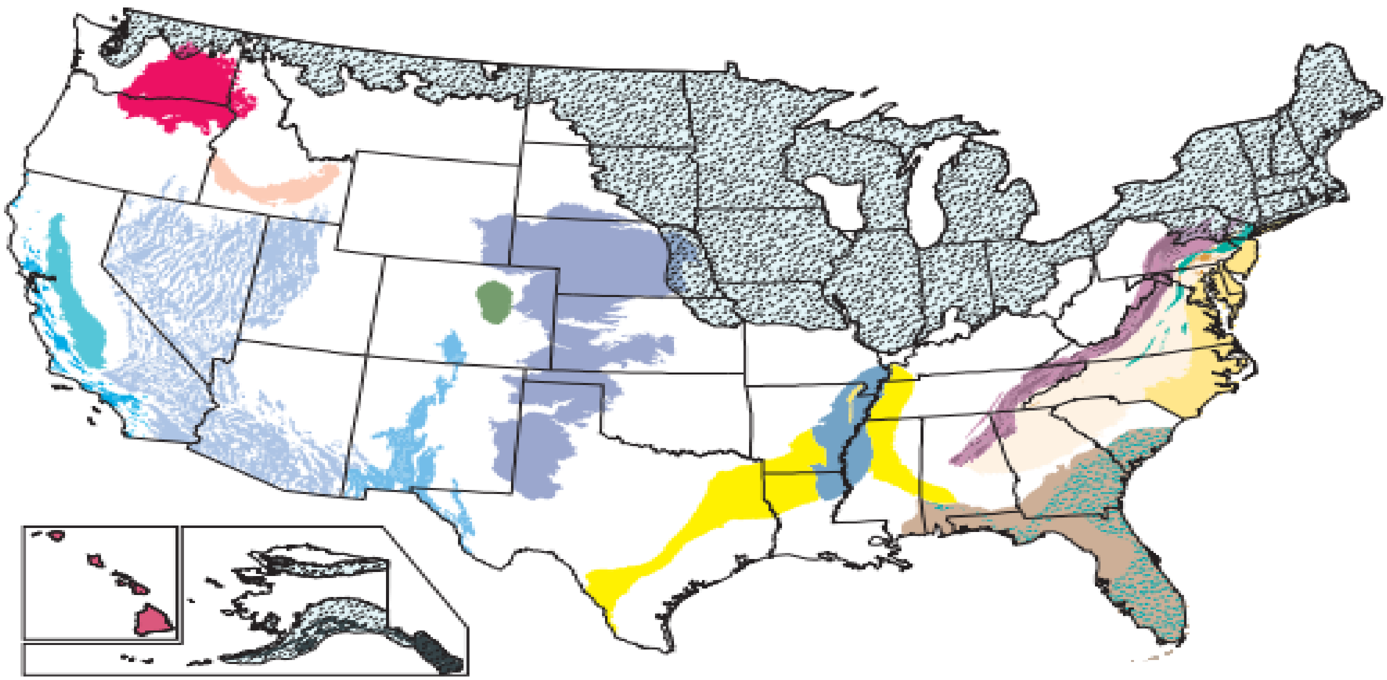
Arsenic

- Groundwater
  - 1/3 of Public Withdrawals
  - 14.6 BGD
  - 90 Million People served

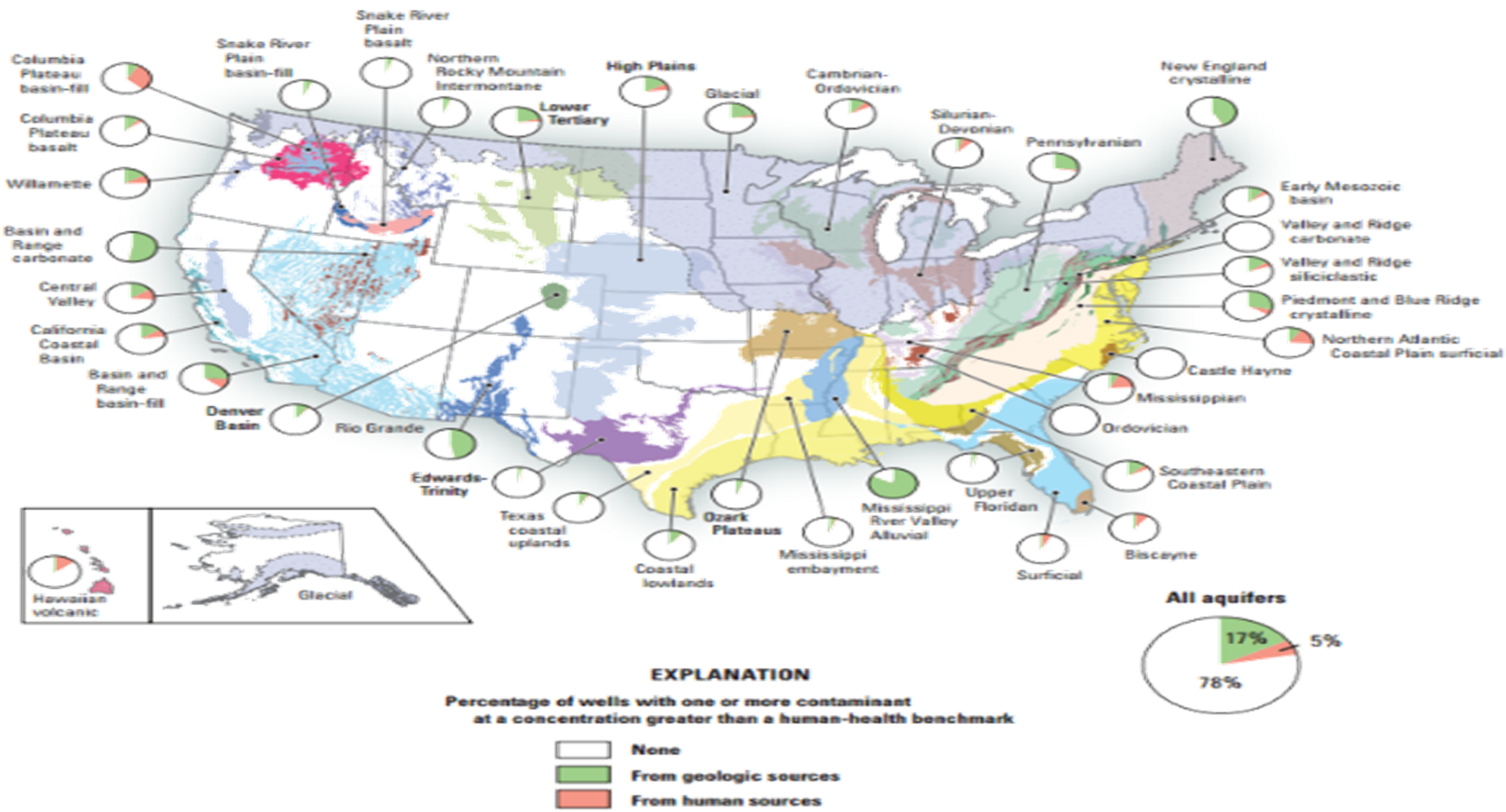
- Surface Water
  - 2/3 of Public Withdrawals
  - 21.9 BGD
  - 170 Million People Served



USGS: Water Quality in Principal Aquifers of the United States, 1991–2010



Exceedances of human-health benchmarks by one or more contaminants



Groundwater Technologies

- **Filter**
  - Biological Filtration
  - Hydrous Manganese Oxide Filtration
  - Oxidation/precipitation/filtration
- **Membrane Processes**
  - Reverse Osmosis
  - Nanofiltration
  - Ultrafiltraiton
  - Microfiltration
- **Sorption**
  - Iron Oxides
  - Manganese Dioxide
  - Granular Activated Carbon
- **IX**
  - Cation Exchange
  - Anion Exchange
  - Electrodialysis Reversal
- **Precipitation**
  - Barium Sulfate Precipitation
  - Excess Lime Softening
  - Pellet Softening
  - Aeration

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Primary Contaminants — Microbial

Category	Process	Giardia Lamblia	Cryptosporidium	Legionella	Heterotrophic plate count (HPC)	Turbidity	Viruses	Total coliforms	Fecal coliforms	E. Coli
Filter	Coagulation- filtration		✓	✓	✓	✓	✓	✓	✓	✓
	Biological Filtration		✓	✓	✓	✓	✓	✓	✓	✓
	Hydrous Manganese Oxide Filtration									
	Oxidation/precipitation/filtration				✓		✓			
Membrane Processes	Reverse Osmosis	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Nanofiltration		✓	✓	✓	✓	✓	✓	✓	✓
	Ultrafiltraiton		✓	✓	✓	✓	✓	✓	✓	✓
	Microfiltration		✓	✓	✓	✓	✓	✓	✓	✓
Sorption	Iron Oxides									
	Manganese Dioxide									
	Granular Activated Carbon									
IX	Cation Exchange									
	Anion Exchange									
	Electrodialysis Reversal	✓	✓	✓	✓	✓	✓	✓	✓	✓
Precipitation	Barium Sulfate Precipitation									
	Excess Lime Softening									
	Pellet Softening									
	Aeration									
Chemical Feed Systems	Ozonation	✓		✓			✓	✓	✓	✓
	Permanganate	✓		✓						
	Chlorine	✓	✓	✓	✓		✓	✓	✓	✓
	Chlorine Dioxide	✓	✓	✓	✓		✓	✓	✓	✓
	Chloramine			✓	✓		✓	✓	✓	✓
	Ultraviolet	✓	✓		✓					
	UV - Peroxide	✓	✓	✓	✓		✓	✓	✓	✓
	Lime									
	Carbon Dioxide									
	Soda Ash									
	Caustic									
	Silicate									
	Polyphosphate									
	Orhtophosphate									
	Limestone									

Primary Contaminants — Disinfectants & Disinfection By Products; Lead and Copper

Category	Process	Bromate	Bromodichloromethane	Bromoform	Chlorite	Chloroform	Dibromochloromethane	Dichloroacetic acid	Haloacetic acids (HAA5)[1]	Trichloroacetic acid	Total Trihalomethanes (TTHMs)[2]	Total Organic Carbon (TOC)	Lead and Copper	Lead	Copper
Filter	Coagulation- filtration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Biological Filtration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Hydrous Manganese Oxide Filtration														
	Oxidation/precipitation/filtration														
Membrane Processes	Reverse Osmosis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Nanofiltration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Ultrafiltraiton	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Microfiltration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Sorption	Iron Oxides														
	Manganese Dioxide														
	Granular Activated Carbon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
IX	Cation Exchange														
	Anion Exchange														
	Electrodialysis Reversal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Precipitation	Barium Sulfate Precipitation														
	Excess Lime Softening													✓	
	Pellet Softening														
	Aeration														
Chemical Feed Systems	Ozonation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Permanganate	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Chlorine	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
	Chlorine Dioxide	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Chloramine	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Ultraviolet	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	UV - Peroxide	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	Lime													✓	✓
	Carbon Dioxide													✓	✓
	Soda Ash													✓	✓
	Caustic													✓	✓
	Silicate													✓	✓
	Polyphosphate													✓	✓
	Orhtophosphate													✓	✓
	Limestone													✓	✓

Primary Contaminants — Inorganics

Category	Process	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cyanide	Fluoride	Mercury	Nickel	Nitrate	Nitrite	Selenium	Thallium
Filter	Coagulation- filtration		✓												
	Biological Filtration		✓												
	Hydrous Manganese Oxide Filtration		✓												
	Oxidation/precipitation/filtration														
Membrane Processes	Reverse Osmosis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Nanofiltration		✓												
	Ultrafiltraiton		✓												
	Microfiltration		✓												
Sorption	Iron Oxides		✓												
	Manganese Dioxide														
	Granular Activated Carbon						✓								
IX	Cation Exchange														
	Anion Exchange		✓							✓		✓		✓	
	Electrodialysis Reversal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Precipitation	Barium Sulfate Precipitation											✓	✓		
	Excess Lime Softening		✓												
	Pellet Softening														
	Aeration									✓					
Chemical Feed Systems	Ozonation														
	Permanganate														
	Chlorine														
	Chlorine Dioxide														
	Chloramine														
	Ultraviolet														
	UV - Peroxide														
	Lime									✓	✓				
	Carbon Dioxide									✓	✓				
	Soda Ash									✓	✓				
	Caustic									✓	✓				
	Silicate									✓	✓				
	Polyphosphate														
	Orhtophosphate									✓	✓				
	Limestone									✓	✓				

Primary Contaminants — Organics; [illegible]

Category	Process	Volatile Organics	Synthetic Organics	Pesticides	Dissolved organic carbon	DBP Precursors	Pharmaceuticals	Gross alpha	Beta and photon emitters[1]	Iodine-131[2]	Combined Radium 226 & 228[3]	Uranium	Strontium 90[2]	Tritium[2]	Radon
Filter	Coagulation- filtration		✓	✓	✓	✓	✓						✓	✓	✓
	Biological Filtration		✓	✓	✓	✓	✓						✓	✓	✓
	Hydrous Manganese Oxide Filtration										✓		✓	✓	✓
	Oxidation/precipitation/filtration														
Membrane Processes	Reverse Osmosis		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Nanofiltration		✓	✓	✓	✓	✓								
	Ultrafiltraiton														
	Microfiltration														
Sorption	Iron Oxides														
	Manganese Dioxide										✓				
	Granular Activated Carbon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
IX	Cation Exchange														
	Anion Exchange		✓		✓										
	Electrodialysis Reversal		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Precipitation	Barium Sulfate Precipitation							✓	✓	✓	✓	✓	✓		
	Excess Lime Softening			✓	✓	✓	✓						✓	✓	✓
	Pellet Softening														
	Aeration	✓											✓		
Chemical Feed Systems	Ozonation	✓	✓	✓	✓	✓	✓								
	Permanganate	✓													
	Chlorine	✓													
	Chlorine Dioxide	✓													
	Chloramine														
	Ultraviolet														
	UV - Peroxide	✓	✓	✓	✓	✓	✓								
	Lime														
	Carbon Dioxide														
	Soda Ash														
	Caustic														
	Silicate														
	Polyphosphate														
	Orhtophosphate														
	Limestone														

Secondary Contaminants

Category	Process	Hardness	Iron	Manganese	Total Dissolved solids	Chloride	Sulfate	Zinc	Color	Taste and Odor	Aluminum	Copper	Corrosivity	Fluoride	Foaming agents	Odor	pH	Silver
Filter	Coagulation- filtration		✓	✓					✓	✓						✓		
	Biological Filtration		✓	✓					✓	✓					✓	✓		
	Hydrous Manganese Oxide Filtration		✓	✓					✓	✓								
	Oxidation/precipitation/filtration		✓	✓					✓									
Membrane Processes	Reverse Osmosis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓				✓
	Nanofiltration	✓	✓	✓	✓				✓									
	Ultrafiltraiton		✓	✓														
	Microfiltration		✓	✓														
Sorption	Iron Oxides																	
	Manganese Dioxide		✓	✓					✓									
	Granular Activated Carbon								✓	✓					✓			
IX	Cation Exchange	✓	✓	✓														
	Anion Exchange						✓		✓		✓							
	Electrodialysis Reversal	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓				✓
Precipitation	Barium Sulfate Precipitation																	
	Excess Lime Softening	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓			✓
	Pellet Softening	✓																
	Aeration															✓		
Chemical Feed Systems	Ozonation								✓	✓					✓	✓		
	Permanganate								✓	✓						✓		
	Chlorine									✓						✓		
	Chlorine Dioxide								✓	✓						✓		
	Chloramine									✓								
	Ultraviolet									✓								
	UV - Peroxide								✓	✓					✓	✓		
	Lime												✓				✓	
	Carbon Dioxide												✓				✓	
	Soda Ash												✓				✓	
	Caustic												✓				✓	
	Silicate		✓	✓									✓				✓	
	Polyphosphate		✓	✓									✓					
	Orhtophosphate												✓					
	Limestone												✓				✓	

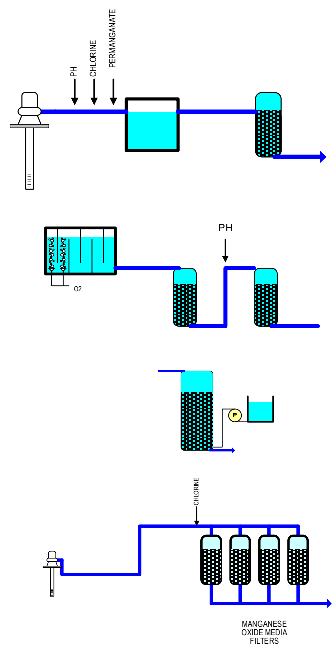
Iron and Manganese Removal

Clark Public Utilities, Vancouver, WA

Southlake Water Treatment Plant

Treatment Technology	Benefits	Drawbacks
Aeration followed by filtration	•No chemical use •Easy to operate	•Entrained air can interfere with filtration if not broken •May require breaking head and repumping •Not effective for manganese removal or iron complexed with organic material •Low filter loading rates for effective removal •High capital cost
Chlorination followed by filtration	•Chlorine often used for disinfection and present at treatment plant	•May require pH adjustment for manganese removal because of slow reactions at low pH •Low filter loading rates for effective removal •Easy to operate •High capital cost
Ozone followed by filtration	•Strong oxidant, requires little reaction time	•May oxidize manganese to permanganate •May oxidize manganese dioxide–containing media to permanganate •Difficult to operate •High capital and operations and maintenance costs
Chlorine dioxide followed by filtration	•Effective for iron complexed with organic material •No trihalomethane formation	•Generated on site with variety of chemicals •Requires careful operation and maintenance •Chlorite is a by-product •High capital cost
Potassium permanganate followed by filtration	•Strong oxidant, requires short reaction times •Can reform manganese dioxide coating on media	•Causes staining if spilled •May be overfed, resulting in pink or purple water
Biological filtration	•Easy to operate •Low operating cost	•Requires start-up period initially and after prolonged shutdowns •May require two stages for iron and manganese removal •High capital cost
Ion exchange	•Easy to operate	•Only effective on reduced forms of iron and manganese •No preoxidation should occur before ion-exchange unit •Fouling is common •Taste may be less palatable than with other methods •High capital and operating costs
Manganese greensand filtration	•Very effective for manganese •Can achieve high loading rates, but often not done	•Often used in combination with anthracite media for iron filtration •Media may crack •Recommended use with permanganate feed
Oxide coated sand filtration	•Effectiveness depends on type, thickness, and oxidation state of coating •Easy to operate	•Effectiveness depends on type, thickness, and oxidation state of coating AU//correct to have this entry for both Benefit and Drawback •Moderate capital cost
Pyrolusite media filtration	•Easy to operate •Can achieve high loading rates •Low operating costs •Very effective for manganese	•Moderate capital cost
Membrane filtration	•Easy to operate •Can achieve high loading rates	•May cause fouling •Chemical preoxidation must be carefully controlled •Moderate to high capital and operating costs
Stabilization, sequestering	•May reduce precipitation in parts of the distribution system	•Iron and manganese will still precipitate in the distribution system, especially where water stays in the system several days or in hot water systems and appliances •Not effective for high levels of iron and manganese
Lime softening	•Can effectively precipitate iron and manganese	•High capital and operating costs •High levels of solids produced •Requires significant operational oversight and maintenance

Treatment Alternatives



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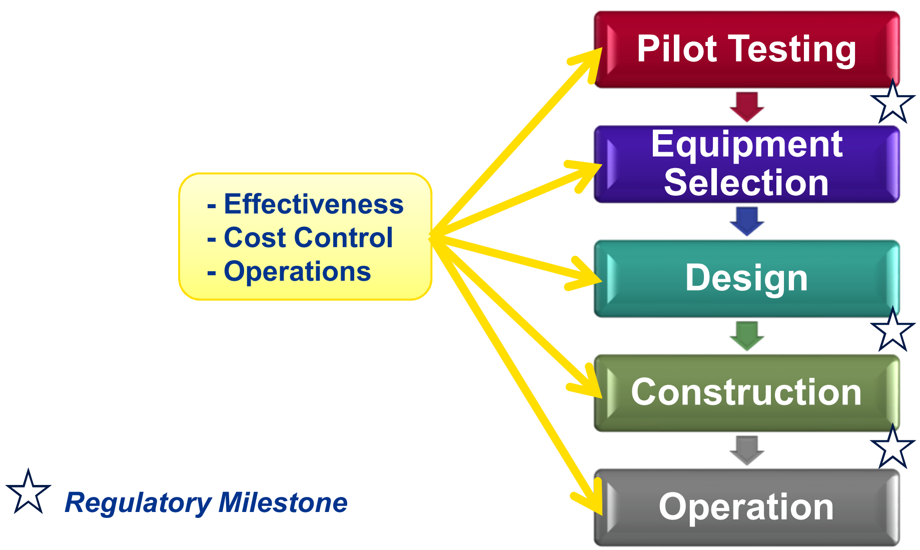
Manganese Treatment Plant Design Approach



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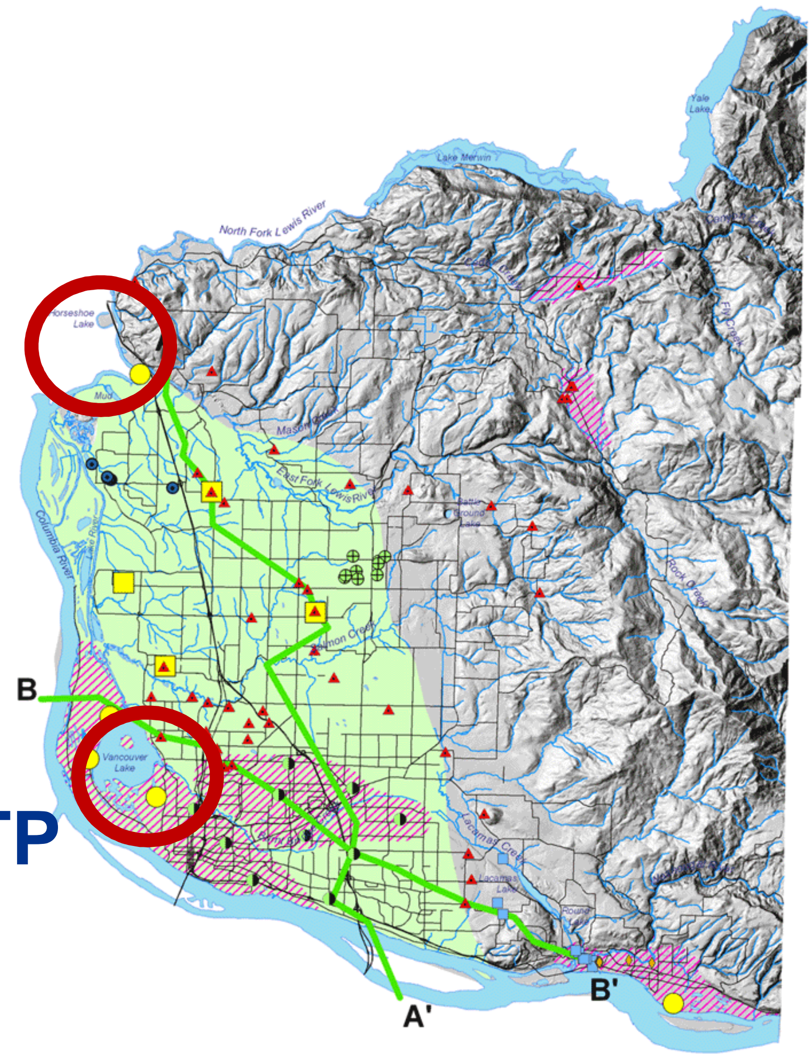
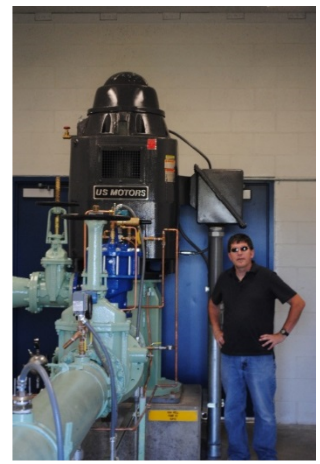
Paradise Point WTP

Carol Curtis WTP



Carol Curtis Water Treatment Plant – 10 MGD
$6 Million Total Construction

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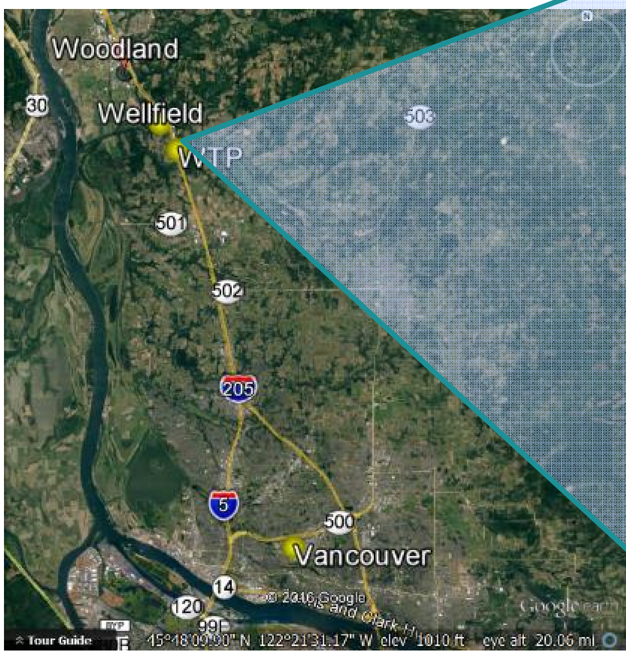
Simplified Operations

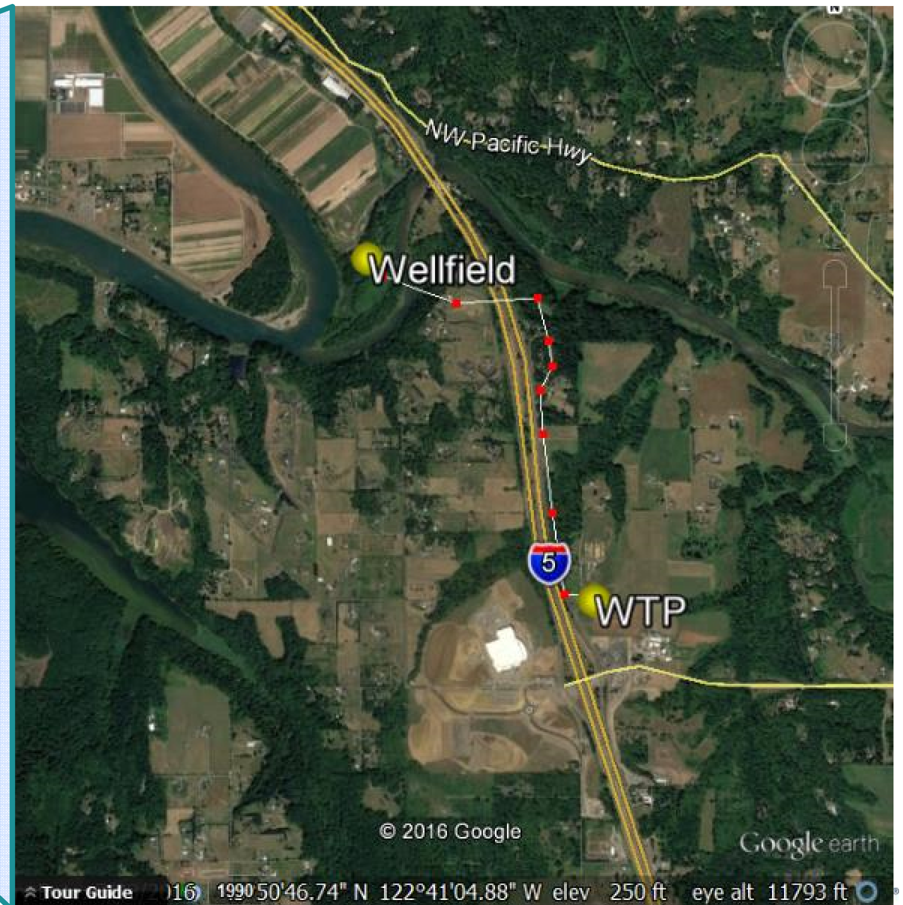
- Automatic backwash – no pumps, simple control
- Minimizes wastewater

Filters

Automated backwash and low chemical use simplify O&M time and costs

Project Location



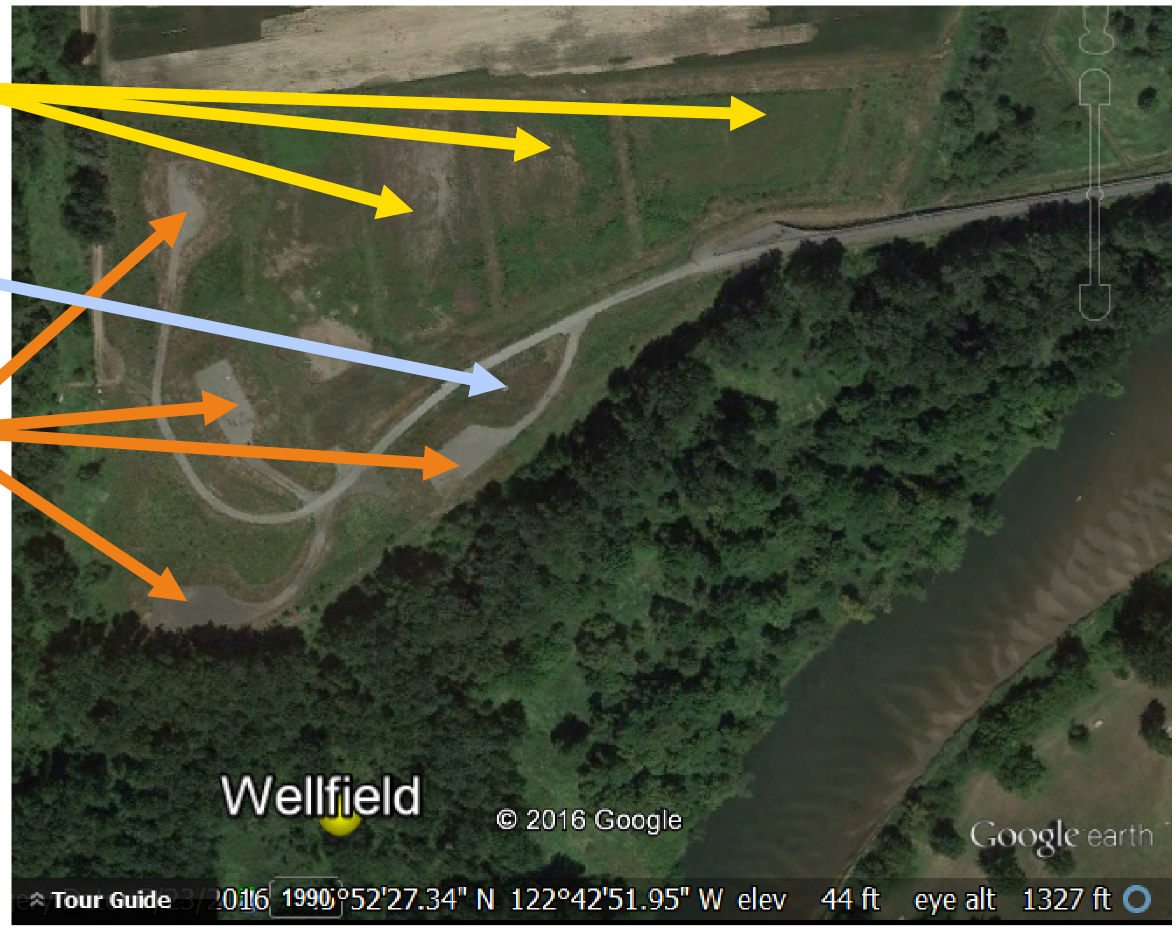


Wellfield and Sludge Pond Site

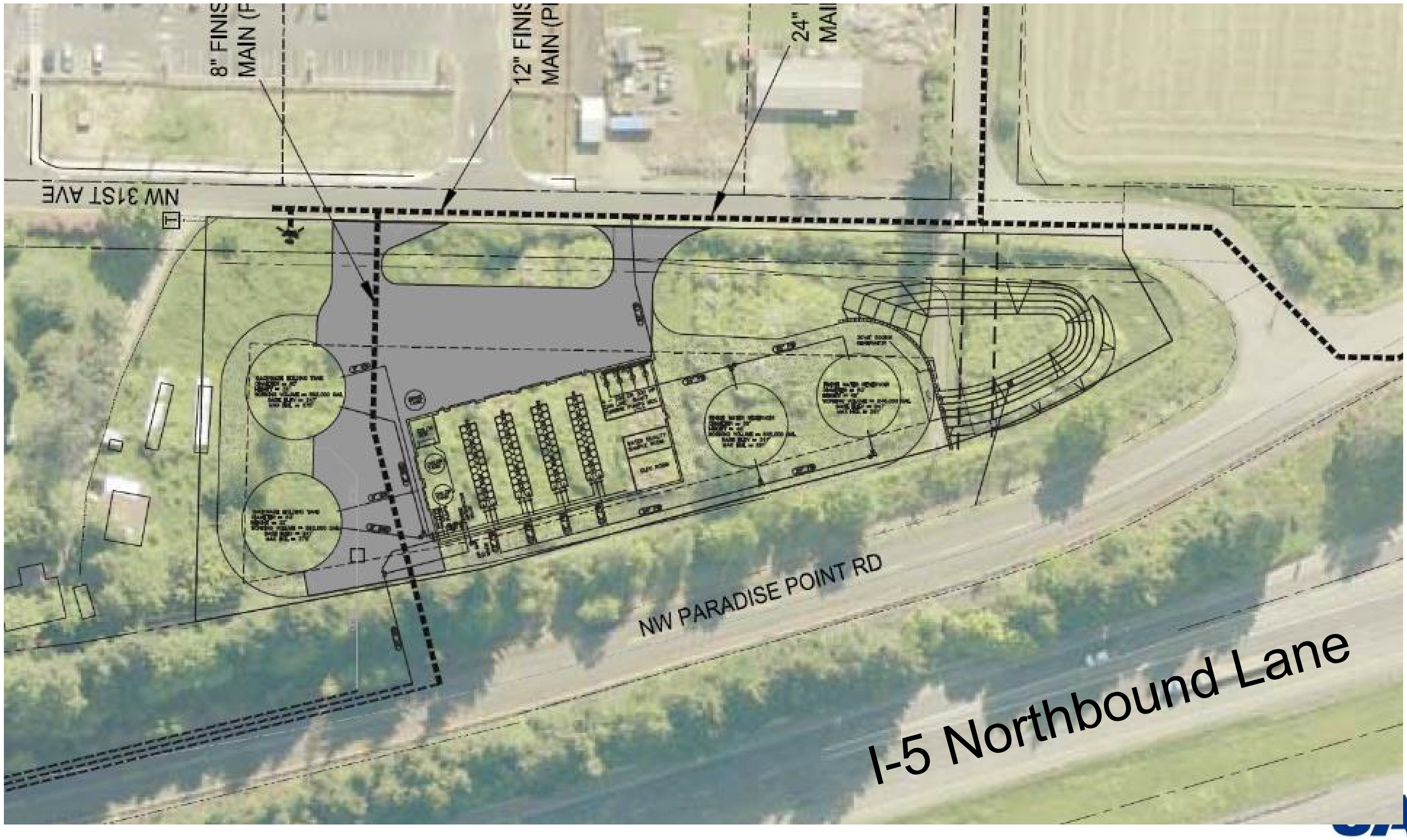
Backwash Ponds

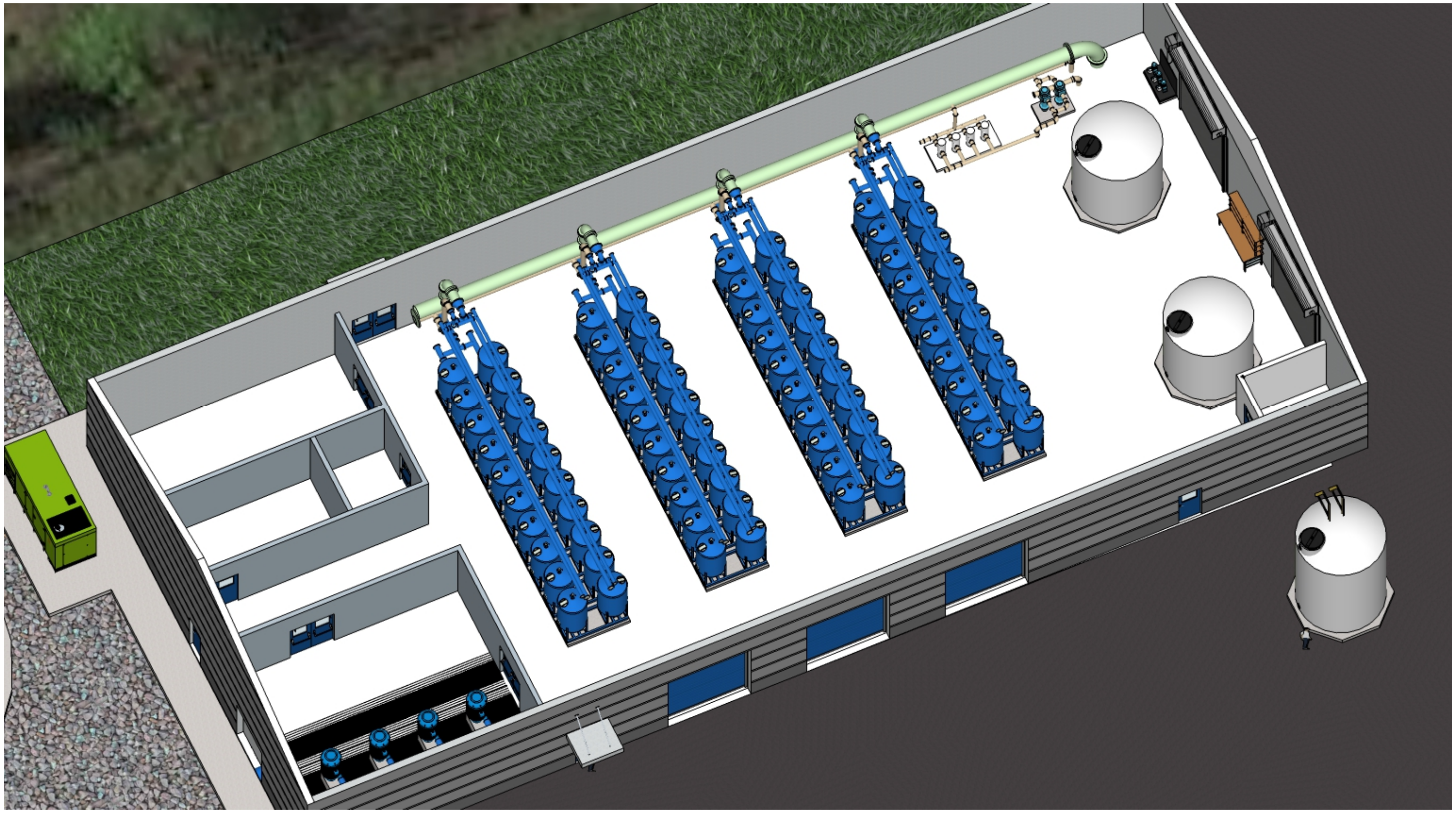
River crossing Termination

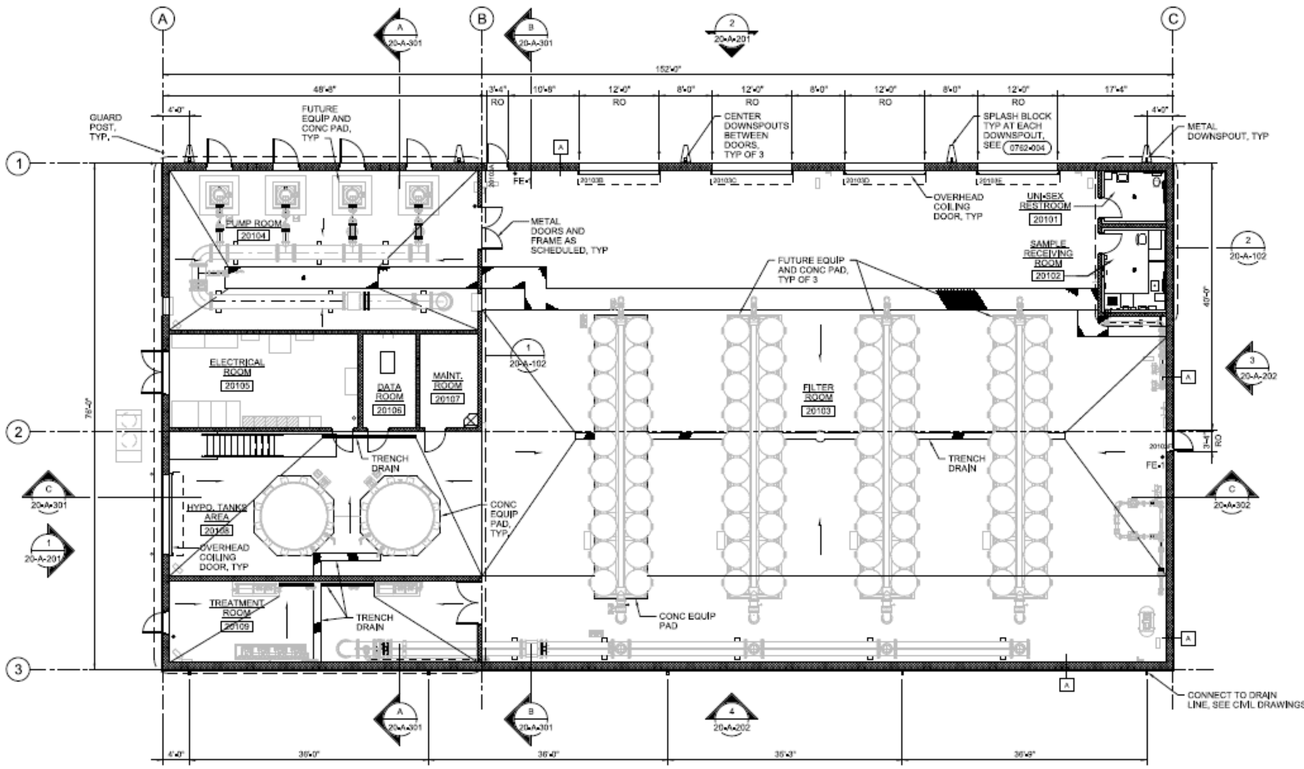
Well Sites



WTP Site


8" FINIS
MAIN (P
12" FINIS
MAIN (P
24"
MAI
NW 31ST AVE
NW PARADISE POINT RD
I-5 Northbound Lane





GROUND FLOOR PLAN
1/8"=1'-0"

Technology Screening – Nitrate

- Raw Water Nitrate Removal Technologies
  - Ion Exchange
    - MIEX
    - Fixed Bed
    - Packed Bed
    - Waste Minimization
  - Alternative Regenerants
  - Reverse Osmosis
  - Electrodialysis Reversal
  - Biological Denitrification
  - Riverbank Filtration
  - Wetlands Treatment
    - Passive
    - Carbon Fed

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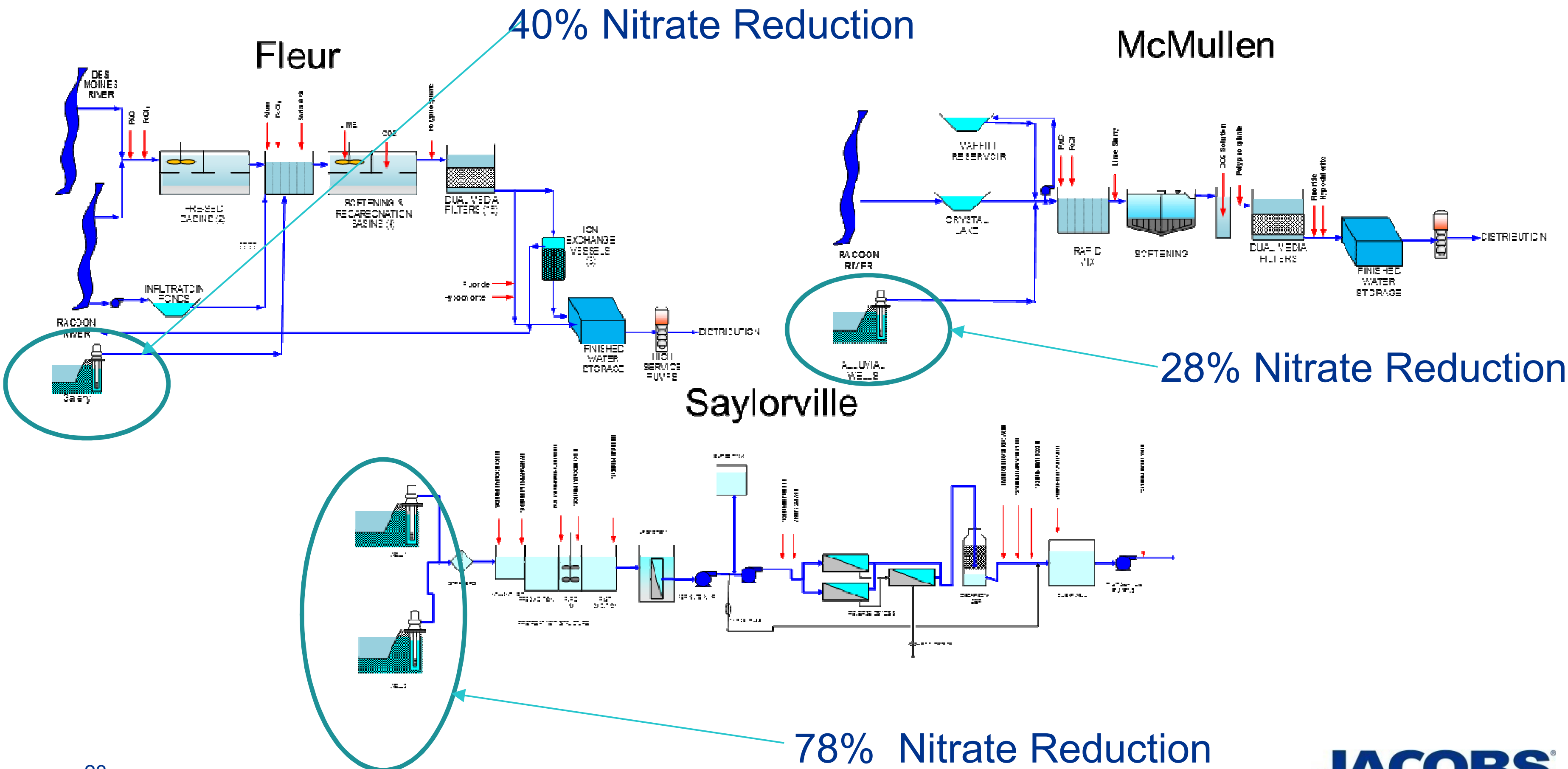
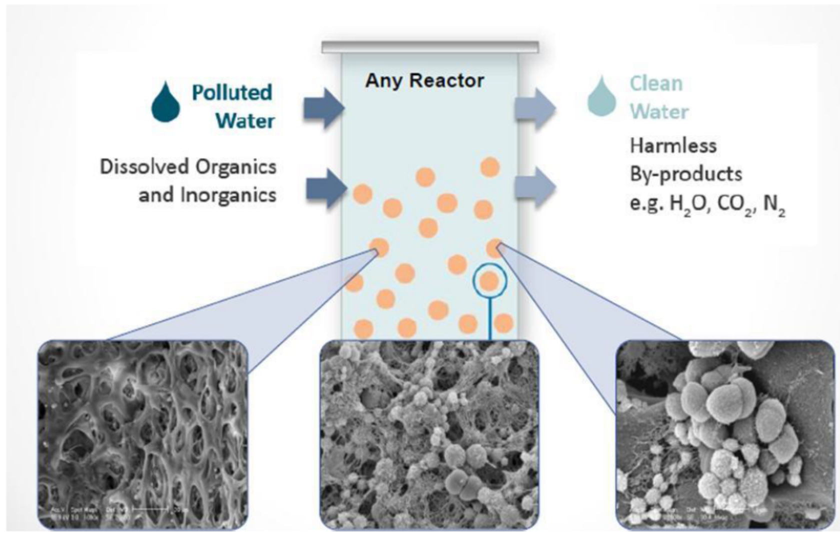


40% Nitrate Reduction
Fleur
McMullen
DES MOINES RIVER
RACCOON RIVER
INFILTRATION PONDS
DUAL MEDIA FILTERS
ION EXCHANGE VESSELS
FINISHED WATER STORAGE
DISTRIBUTION
CRYSTAL LAKE
RAPID MIX
SOFTENING
ALLUVIAL WELLS
28% Nitrate Reduction
Saylorville
78% Nitrate Reduction

Phase 3 Nitrate Pilot Testing- Microvi

Microvi's bacteria are encased within porous beads about 10 mm in diameter



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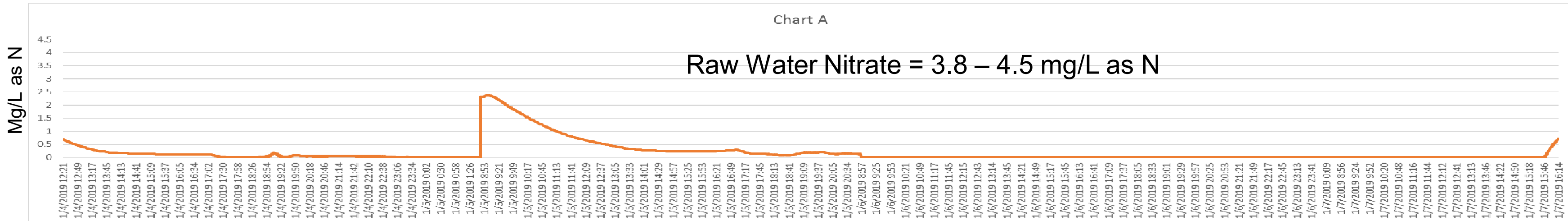
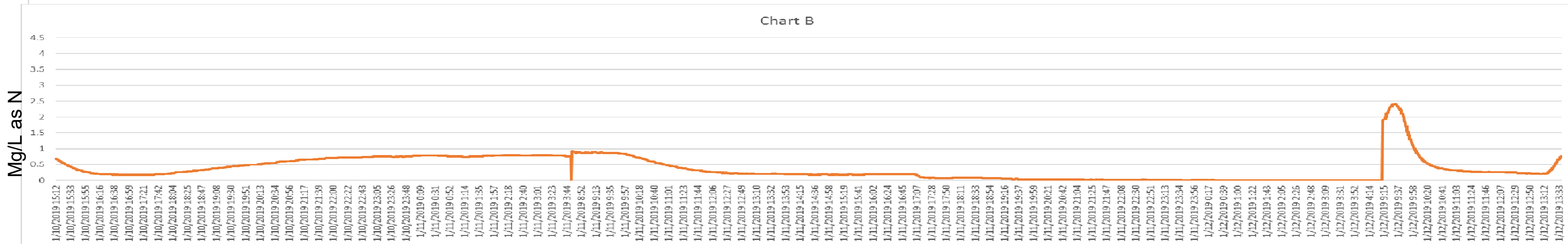
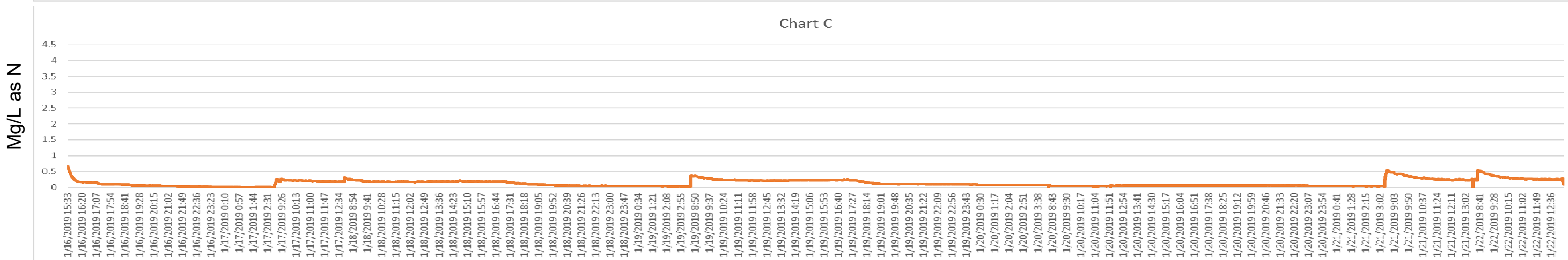
Nitrate Pilot Testing Results







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Planning Criteria	Shallow Wells	Deep Wells	Total Plant Flow	Existing Systemm
Number of Wells	10	10	20	
Operating Flow, gpm	1,000	1,000	2,000	
Raw Water Quality				
pH, S.U.	8.0	8.5	8.3	7.6
Temperature, °C	10	10	10	14.6
Total Dissolved Solids, mg/L	319	238	279	237
Total Hardness, mg/L as $CaCO_3$	129	51	90	114
Iron, Total, mg/L	0.46	0.02	0.24	<0.03
Manganese, Total, mg/L	0.161	0.031	0.1	0.025
Calcium, mg/L	27	12	20	24.6
Alkalinity, Bicarbonate, mg/L as $CaCO_3$	231	164	198	211
Silica, mg/L	51	35	43	45
Chloride, mg/L	10	5	8	7
Sulfate, mg/L	17	7	12	11
Ammonia, mg/L	3.3	6.8	5.1	0.11
Orthophosphate, mg/L	0.285	0.125	0.205	0.11
Threshold odor number (T.O.N).	17	4	11	4
MPA Risk Score	4	4		

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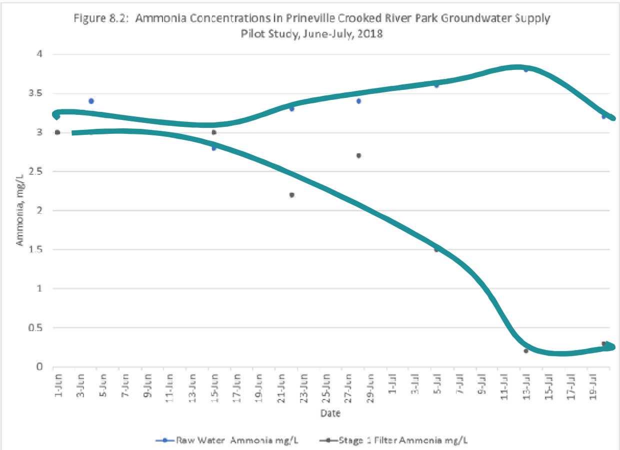
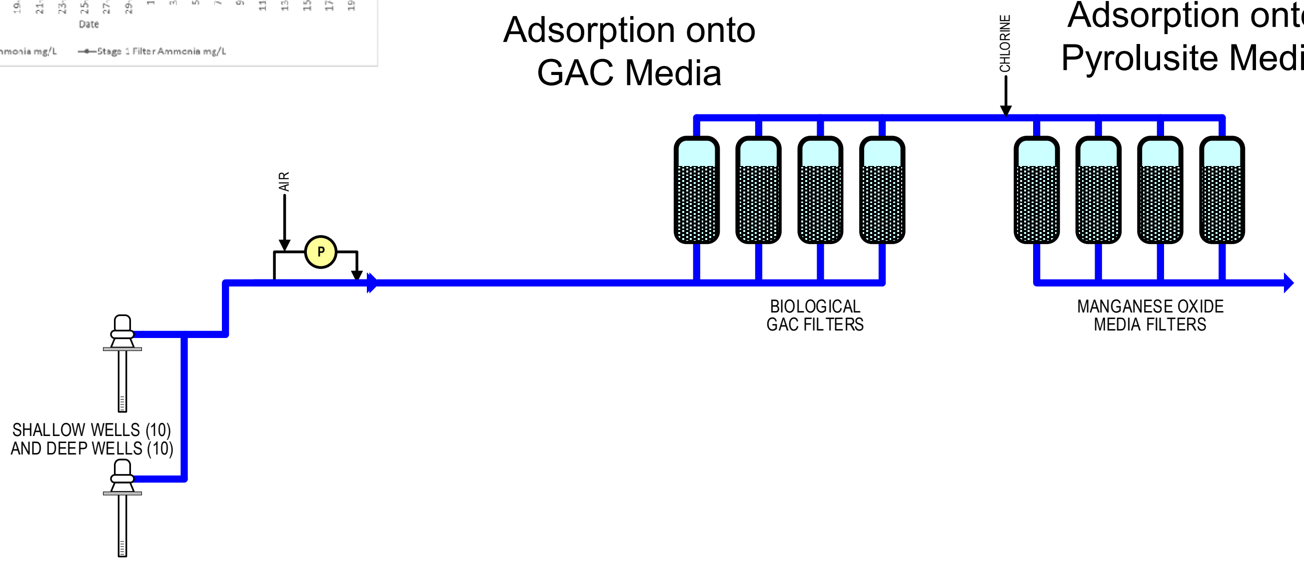
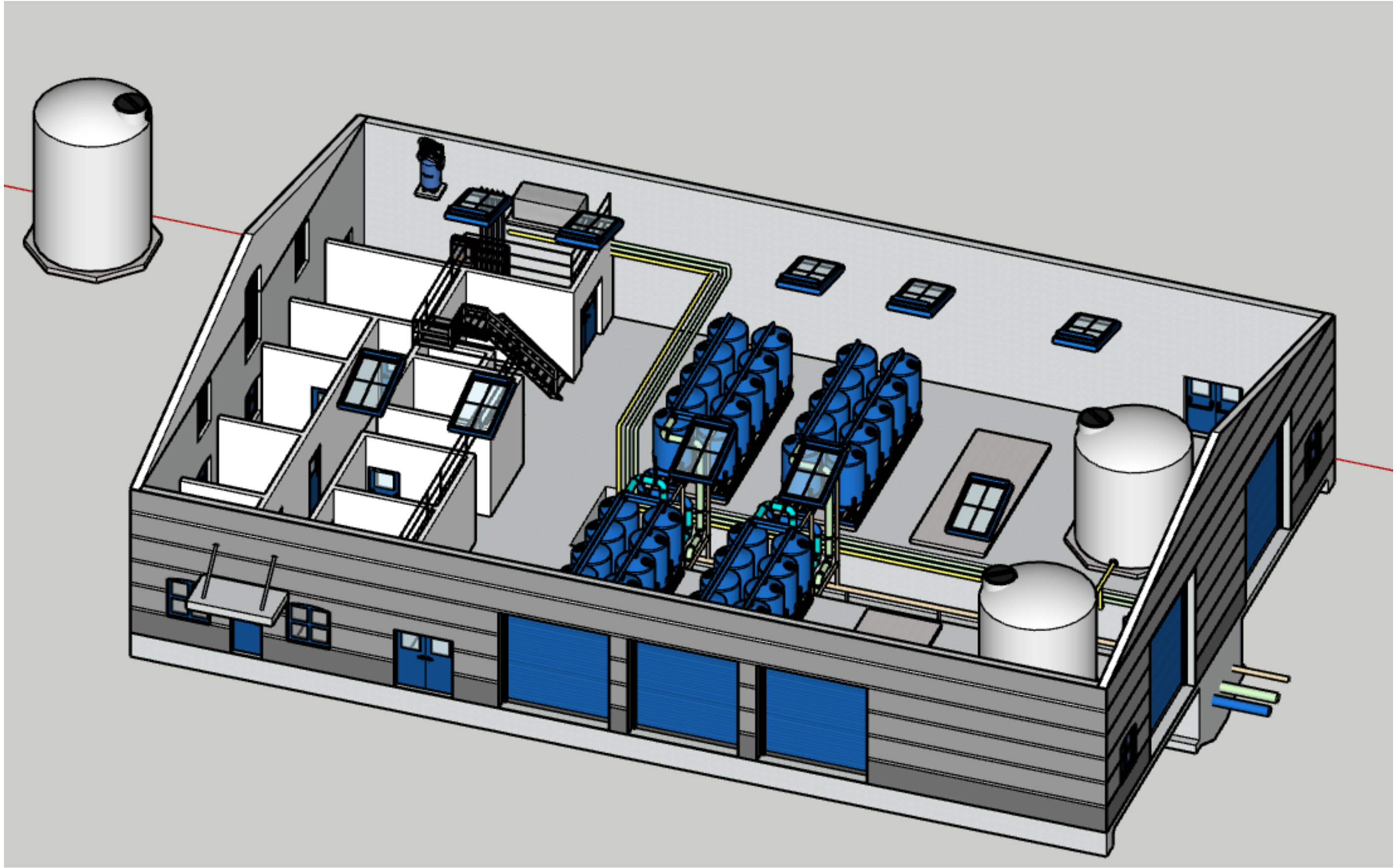
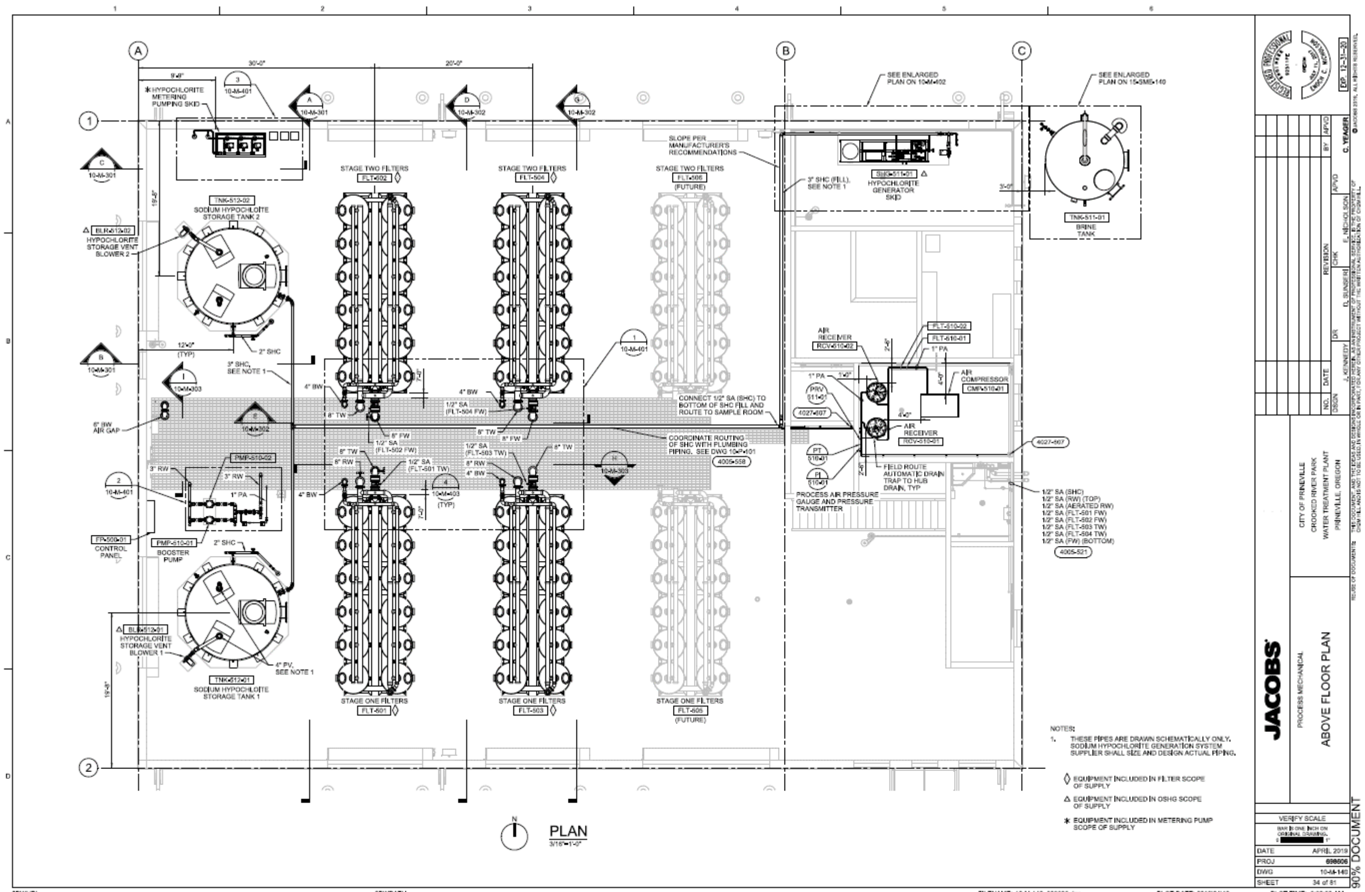


Ammonia Oxidation and Hydrogen Sulfide Adsorption onto GAC Media

Manganese Adsorption onto Pyrolusite Media






STAGE TWO FILTERS
STAGE ONE FILTERS
SODIUM HYPOCHLORITE STORAGE TANK 2
SODIUM HYPOCHLORITE STORAGE TANK 1
HYPOCHLORITE GENERATOR SKID
BRINE TANK
AIR COMPRESSOR
AIR RECEIVER
BOOSTER PUMP
CONTROL PANEL
PLAN
NOTES:
1. THESE PIPES ARE DRAWN SCHEMATICALLY ONLY. SODIUM HYPOCHLORITE GENERATION SYSTEM SUPPLIER SHALL SIZE AND DESIGN ACTUAL PIPING.
EQUIPMENT INCLUDED IN FILTER SCOPE OF SUPPLY
EQUIPMENT INCLUDED IN OSHG SCOPE OF SUPPLY
EQUIPMENT INCLUDED IN METERING PUMP SCOPE OF SUPPLY
JACOBS
PROCESS MECHANICAL
ABOVE FLOOR PLAN
CITY OF PRINEVILLE
CROOKED RIVER PARK
WATER TREATMENT PLANT
PRINEVILLE, OREGON
90% DOCUMENT

PFAS Uses & Products

- Heat, oil, stain, and grease resistant coatings
- Clothing
- Furniture
- Carpet stain protection
- Food packaging
- Paper coating
- Non-stick cooking surfaces
- Electrical wire insulation
- Chromium plating mist suppressants
- Photolithographic chemicals
- Many other uses

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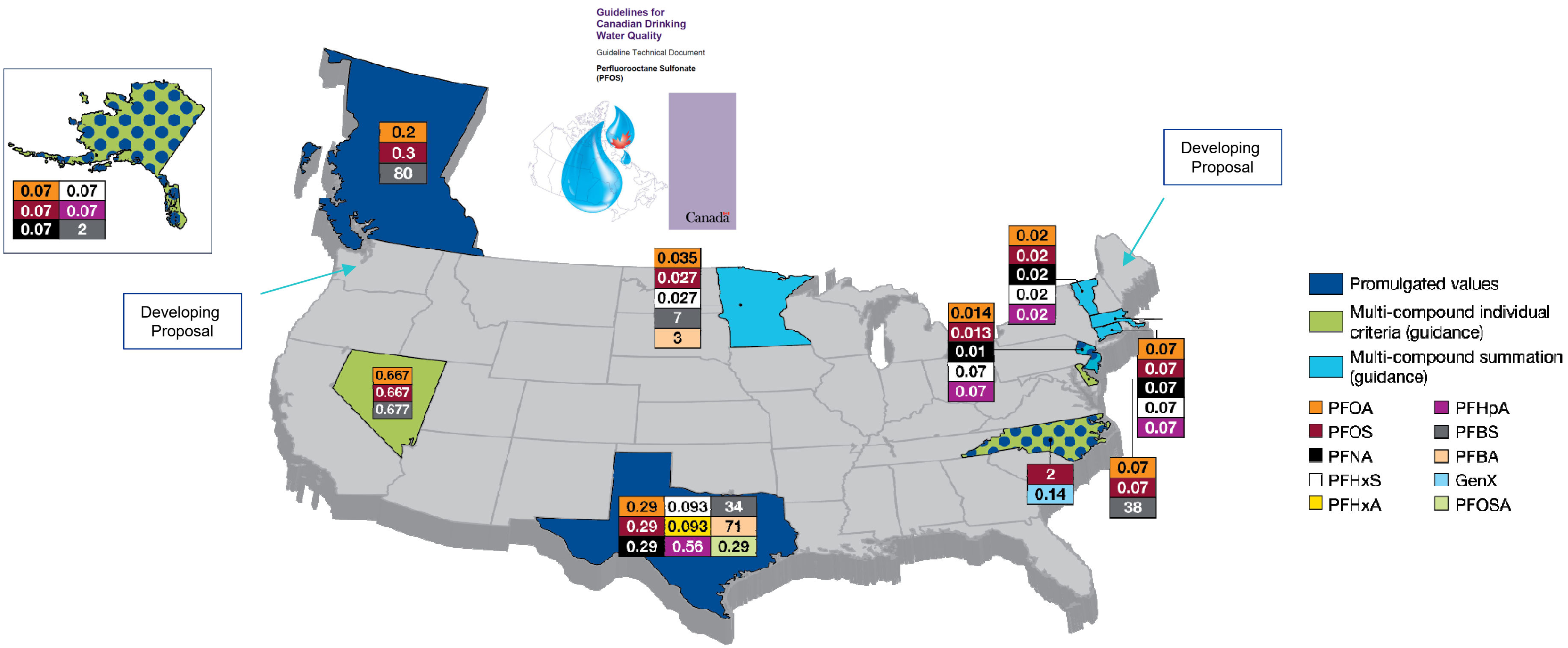

Guidelines for Canadian Drinking Water Quality
Guideline Technical Document
Perfluorooctane Sulfonate (PFOS)
Canada
0.07 0.07
0.07 0.07
0.07 2
0.2
0.3
80
Developing Proposal
0.667
0.667
0.677
0.035
0.027
0.027
7
3
0.29 0.093 34
0.29 0.093 71
0.29 0.56 0.29
0.014
0.013
0.01
0.07
0.07
0.02
0.02
0.02
0.02
0.02
Developing Proposal
0.07
0.07
0.07
0.07
0.07
2
0.14
0.07
0.07
38
Promulgated values
Multi-compound individual criteria (guidance)
Multi-compound summation (guidance)
PFOA
PFOS
PFNA
PFHxS
PFHxA
PFHpA
PFBS
PFBA
GenX
PFOSA

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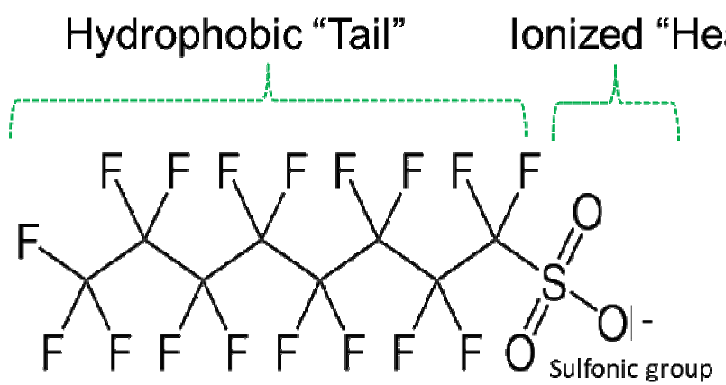
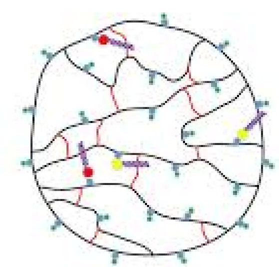
PFOS - Perfluoroalkyl Sulfonic Acid



GAC
removes by adsorption primarily using hydrophobic "Tail"

Selective IX Resins
Likely removes by both ion exchange and adsorption using both "Head" & "Tail"



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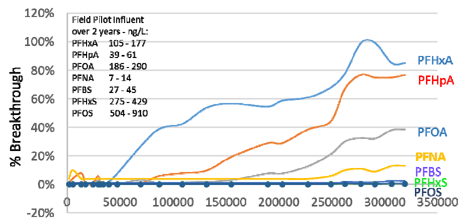
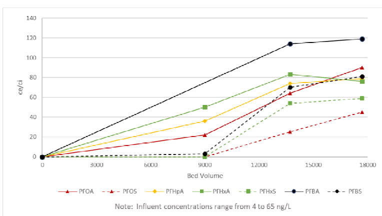
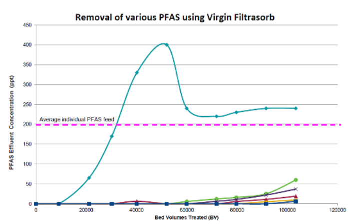
PFAS Preferential Adsorption



- **IX** Pilot study in PA
- PFHxA < PFHpA < PFOA < PFNA < PFBS < PFHxS < PFOS



- **GAC** Pilot study in NC
- PFBA < PFHxA < PFHpA < PFOA < PFBS < PFHxS < PFOS



- **GAC** RSSCT
- PFBA < PFHxA < PFBS < PFOA < PFHxS < PFOS

Source: Purolite; Black & Veatch; Calgon

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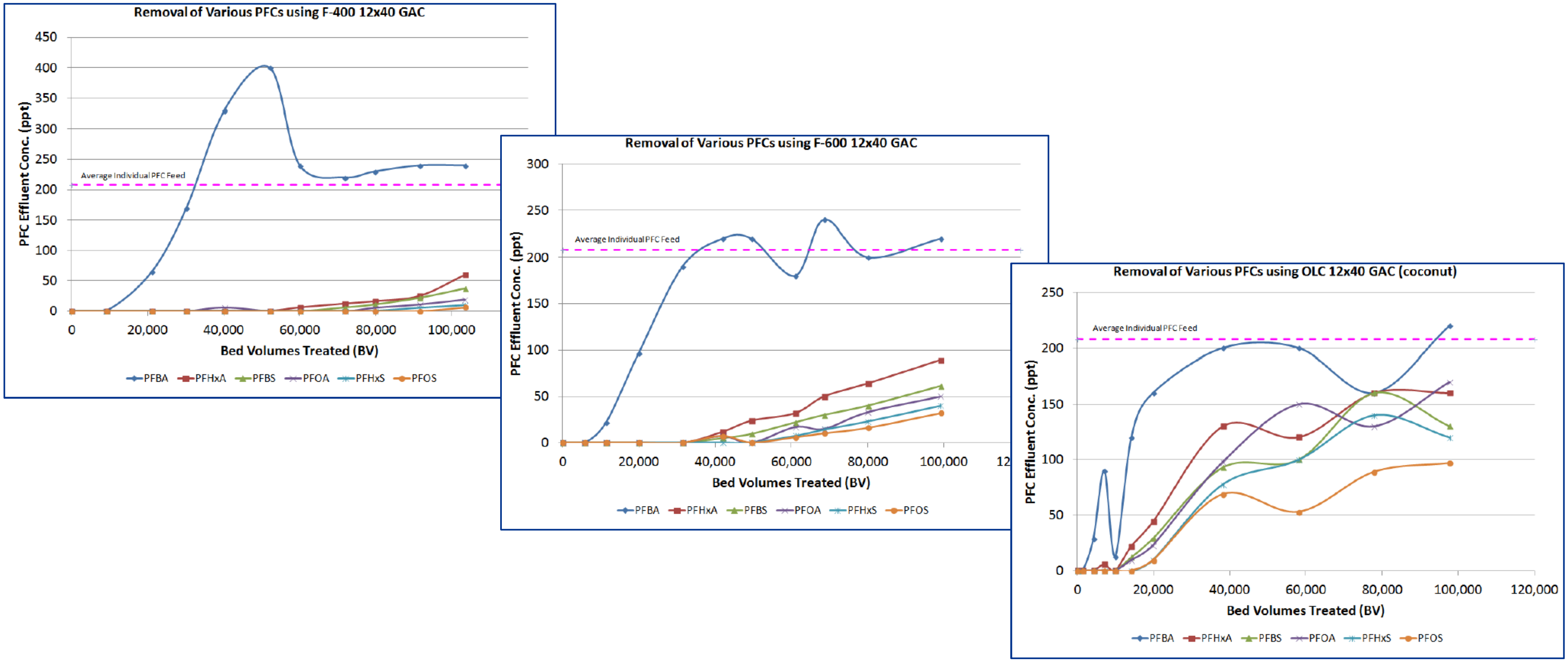
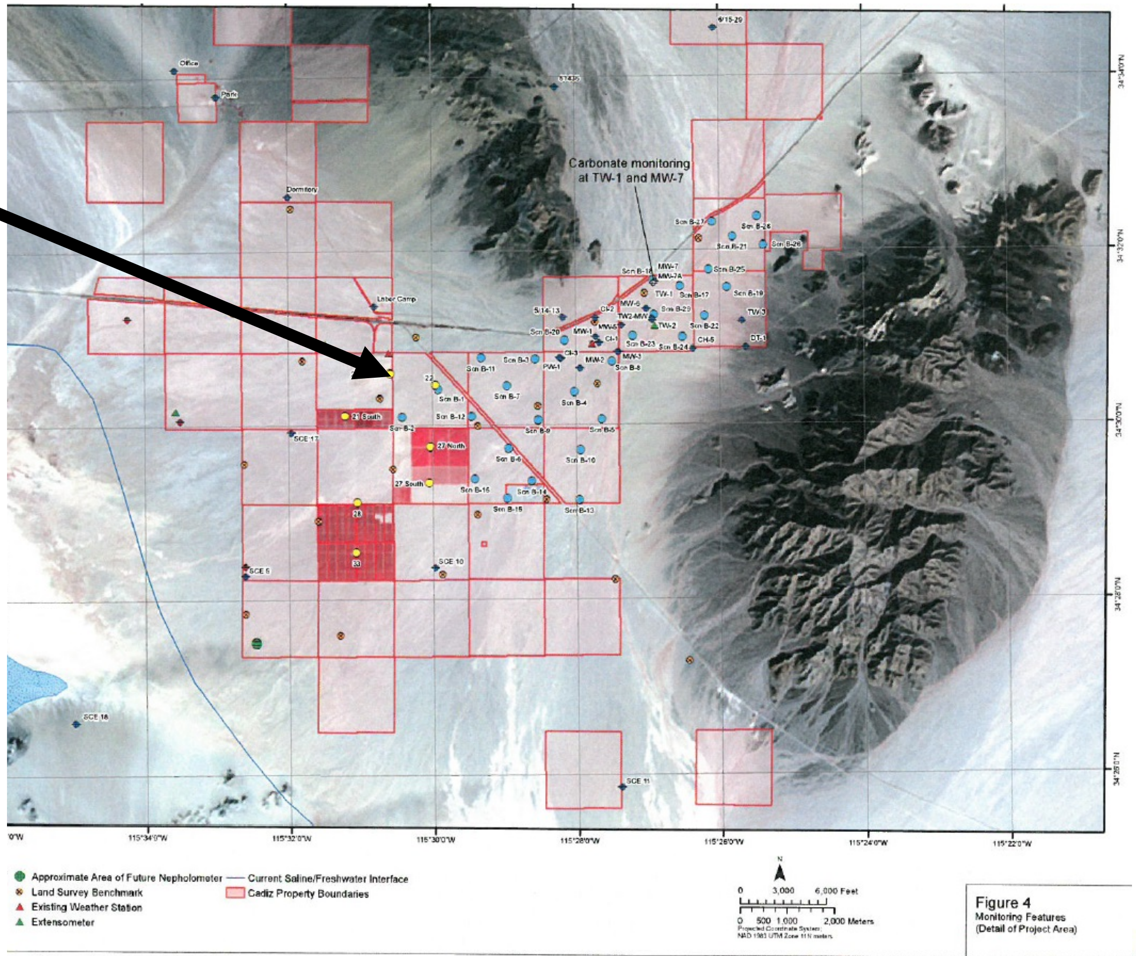
Comparing Carbon Types



Source: Calgon, 2017

Cadiz Well 21N



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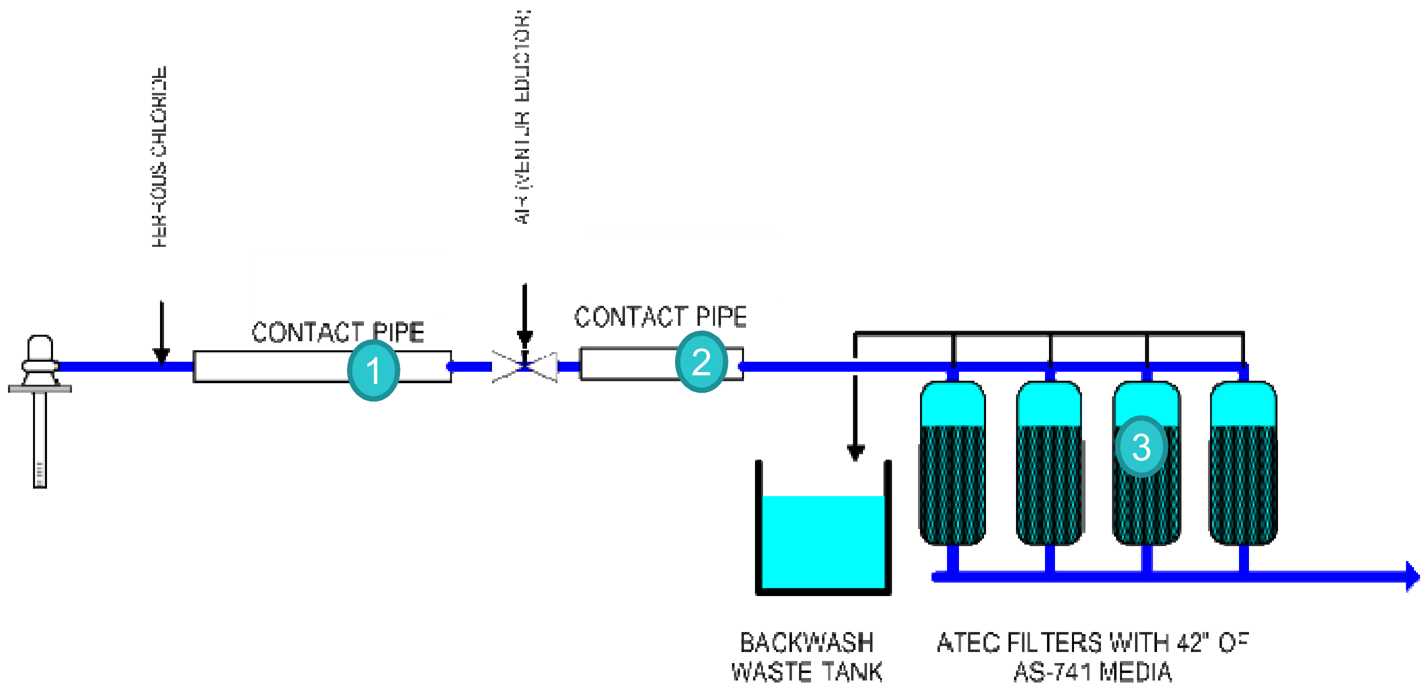
Parameter	Arsenic	Hexavalent Chromium	Total Chromium	Manganese	Iron	Nitrate	TDS	pH
Units	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L as N	µg/L	S. U.
Drinking Water Standard	10[1]	Previously 10[3]	50[1]	50[2]	0.3[2]	10[1]	500[2]	6-9[2]
Well 2IN	9.3	21	18.6	2.7	<0.02	3.5	254	8.4
Cadiz "Representative Average"	6.9	12.9	13.4	15.4	1.6	3.7	314	8.1

Notes:
1 – Primary MCL
2 – Secondary MCL
3 – Previous primary MCL, currently no standard

Chromium and Arsenic Pilot Testing - Reduction/Coagulation/Filtration (RCF) Treatment

1. Pipeline Reduction of Hexavalent Chromium,
2. Followed Pipeline Oxidation of Iron with Air,
3. Followed by Filtration

Pilot Equipment was Supplied By ATEC Systems



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Phase 1 Pilot Testing – 2015

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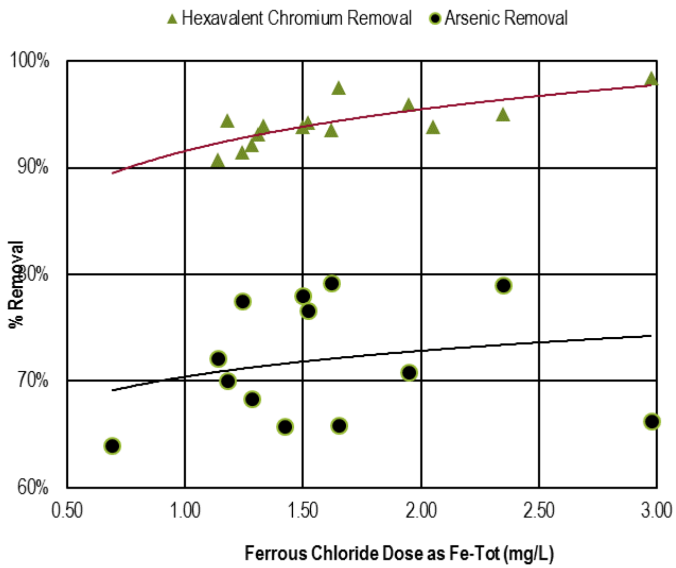
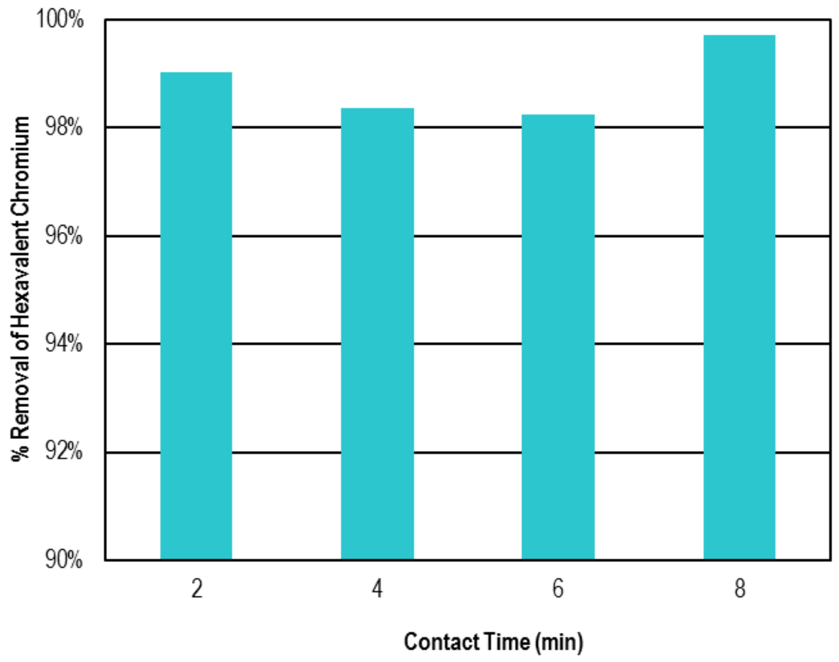
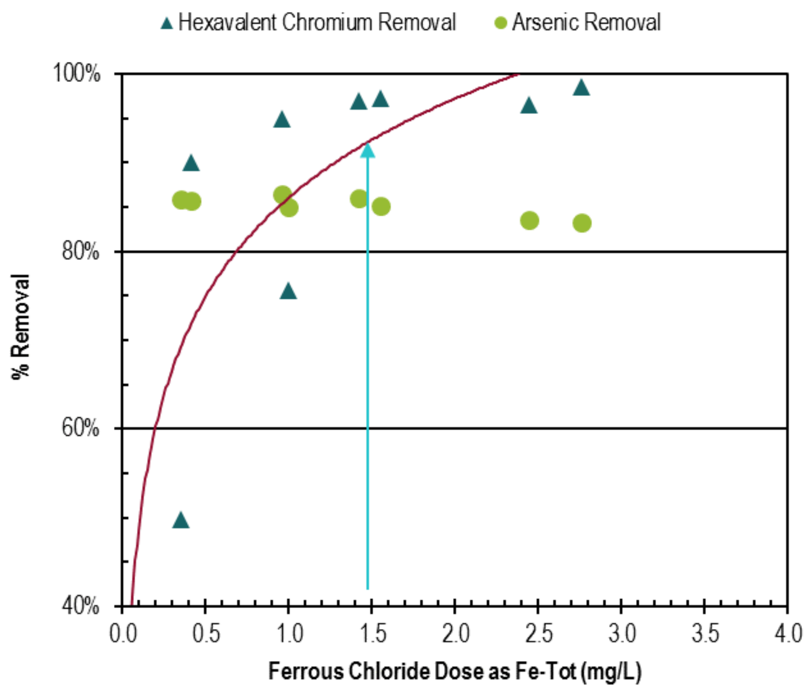
Phase 1 Pilot Testing Results - 2015



Well 21 N Phase 1 Operating Conditions			
Parameter	Average Value		
Flow	4.6 gpm		
Loading Rate	5.9 gpm/sf		
Differential Pressure	2 – 3 psi		
Water Quality Results			
Parameter	Raw Water	Treated Water	Percent Removal
Hexavalent chromium	18.91 µg/L	0.99 µg/L	95%
Total chromium	28.42 µg/L	1.60 µg/L	91%
Arsenic	7.15 µg/L	1.84 µg/L	79%

Phase 1 Pilot Testing





Phase 2 Pilot Testing – 100 gpm, 6 months

Pilot Testing Equipment from Atec Systems, Hollister, CA

Phase 2 Sampling Program: April – Sept, 2018

- Weekly Tests
- Intensive Tests: Hourly for Full Filter Run

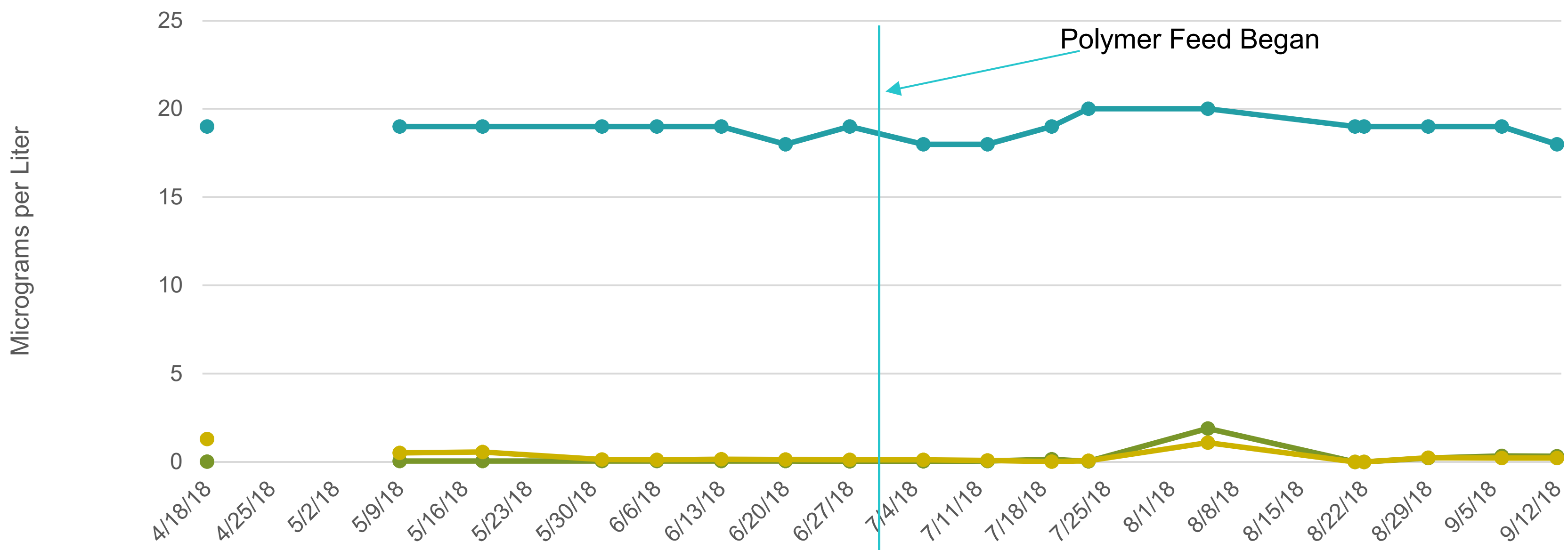
Month	Week	Monitoring Schedule
Month 1	Week 1	Hourly Sampling
	Weeks 2, 3 and 4	Weekly Sampling
Month 2	Week 1	Hourly Sampling
	Weeks 2, 3 and 4	Weekly Sampling
Month 3	Week 1	Hourly Sampling
	Weeks 2, 3 and 4	Weekly Sampling
Month 4	Week 1	Hourly Sampling
	Weeks 2, 3 and 4	Weekly Sampling
Month 5	Week 1	Hourly Sampling
	Weeks 2, 3 and 4	Weekly Sampling
Month 6	Week 1	Hourly Sampling
	Weeks 2, 3 and 4	Weekly Sampling

Data is a mix of lab samples and field tests

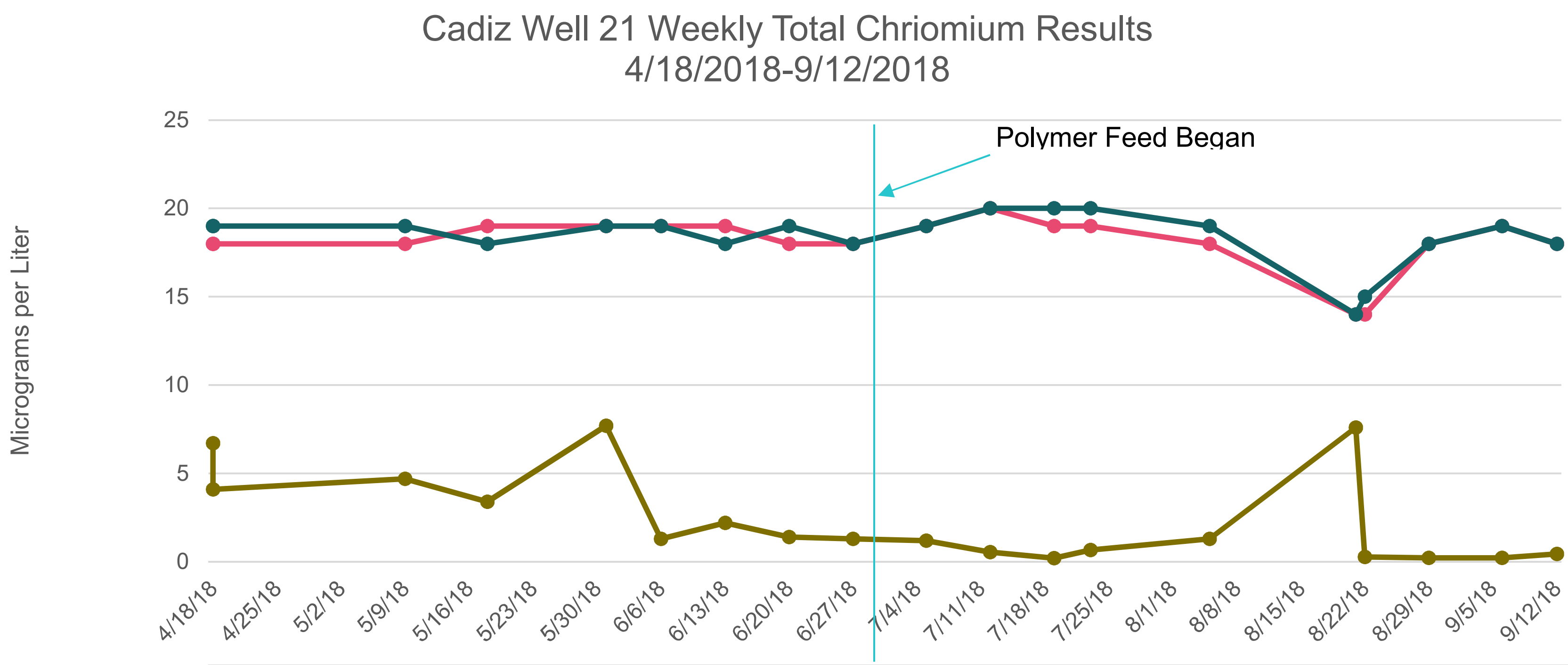
Parameter	Type of Monitoring	Raw Water	Filter Inlet	Filter Outlet
Iron, Total	Grab Sample, Field Test	Weekly	Weekly	21/week
Manganese, Total	Grab Sample, Field Test	Weekly	Weekly	4/week
Arsenic, Total	Grab Sample, Laboratory Test	Weekly	Weekly	4/week
Chromium, Total	Grab Sample, Laboratory Test	Weekly	Weekly	4/week
Hexavalent Chromium	Grab Sample, Laboratory Test	Weekly	Weekly	4/week
Pressure	Reading		Weekly	Weekly
Water Flow	Reading		Weekly	Weekly
Air Flow	Reading		Weekly	Weekly
Ferrous Chloride Dose	Tested with a Calibration Column on Suction Line, with each change in dose.			
pH	Grab Sample, Field Test		Weekly	Weekly
Dissolved Oxygen	Grab Sample, Field Test, Probe		Weekly	Weekly
Air Temperature	Grab	Weekly		
Water Temperature	Grab	Weekly		

ch2m: JACOBS

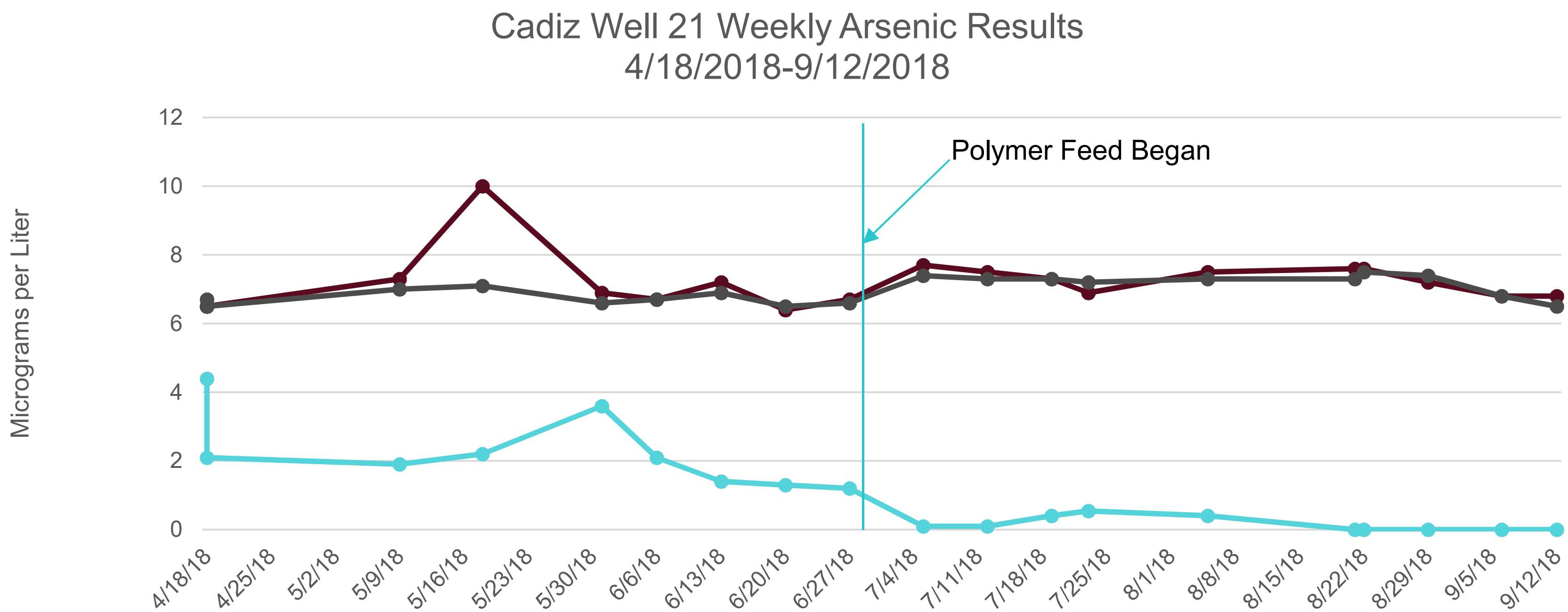
Cadiz Well 21N Weekly Hexavalent Chromium Results
4/18/2018-9/12/2018



	4/18/18	4/18/18	5/9/18	5/18/18	5/31/18	6/6/18	6/13/18	6/20/18	6/27/18	7/5/18	7/12/18	7/19/18	7/23/18	8/5/18	8/21/18	8/22/18	8/29/18	9/6/18	9/12/18
Raw	19		19	19	19	19	19	18	19	18	18	19	20	20	19	19	19	19	18
Filter Influent	0.022		0.046	0.050	0.053	0.053	0.053	0.056	0.042	0.028	0.05	0.154	0.042	1.9	0	0	0.23	0.34	0.33
Filter Effluent	1.3		0.512	0.565	0.139	0.123	0.148	0.134	0.123	0.112	0.083	0.024	0.066	1.1	0	0	0.24	0.23	0.22



	4/18/18	4/18/18	5/9/18	5/18/18	5/31/18	6/6/18	6/13/18	6/20/18	6/27/18	7/5/18	7/12/18	7/19/18	7/23/18	8/5/18	8/21/18	8/22/18	8/29/18	9/6/18	9/12/18
Raw	18	18	18	19	19	19	19	18	18	19	20	19	19	18	14	14	18	19	18
Filter Influent	19	19	19	18	19	19	18	19	18	19	20	20	20	19	14	15	18	19	18
Fil;ter Effluent	6.7	4.1	4.7	3.4	7.7	1.3	2.2	1.4	1.3	1.2	0.54	0.2	0.66	1.3	7.6	0.28	0.23	0.23	0.45



	4/18/18	4/18/18	5/9/18	5/18/18	5/31/18	6/6/18	6/13/18	6/20/18	6/27/18	7/5/18	7/12/18	7/19/18	7/23/18	8/5/18	8/21/18	8/22/18	8/29/18	9/6/18	9/12/18
Raw	6.5	6.5	7.3	10	6.9	6.7	7.2	6.4	6.7	7.7	7.5	7.3	6.9	7.5	7.6	7.6	7.2	6.8	6.8
Filter Influent	6.7	6.5	7	7.1	6.6	6.7	6.9	6.5	6.6	7.4	7.3	7.3	7.2	7.3	7.3	7.5	7.4	6.8	6.5
Filter Effluent	4.4	2.1	1.9	2.2	3.6	2.1	1.4	1.3	1.2	0.1	0.1	0.4	0.54	0.4	0	0	0	0	0

Residuals Testing Results

Parameter/Date	TCLP Result	TCLP Regulatory Limit[a]	TTLC Result	TTLC Regulatory Limit[b]	STLC Result	STLC Reglatory Limit[b]
Arsenic/8-22-18 Arsenic/9-12-18	<0.1 mg/L 0.487 mg/L	5.0 mg/L √	541 mg/kg 623 mg/L	2,500 mg/kg √	0.662 mg/L 4.15 mg/L	5.0 mg/L √
Chromium/8-22-18 Chromium/9-12-18	<0.1 mg/L <0.1 mg/L	5.0 mg/L √	1,869 mg/kg 2,262 mg/kg	2,500 mg/kg √	13.1 mg/L 13.6 mg/L	560 mg/L if TCLP is passed √

a. 40 CFR 261.24
b. CA 22 CCR 66261.24 Table II

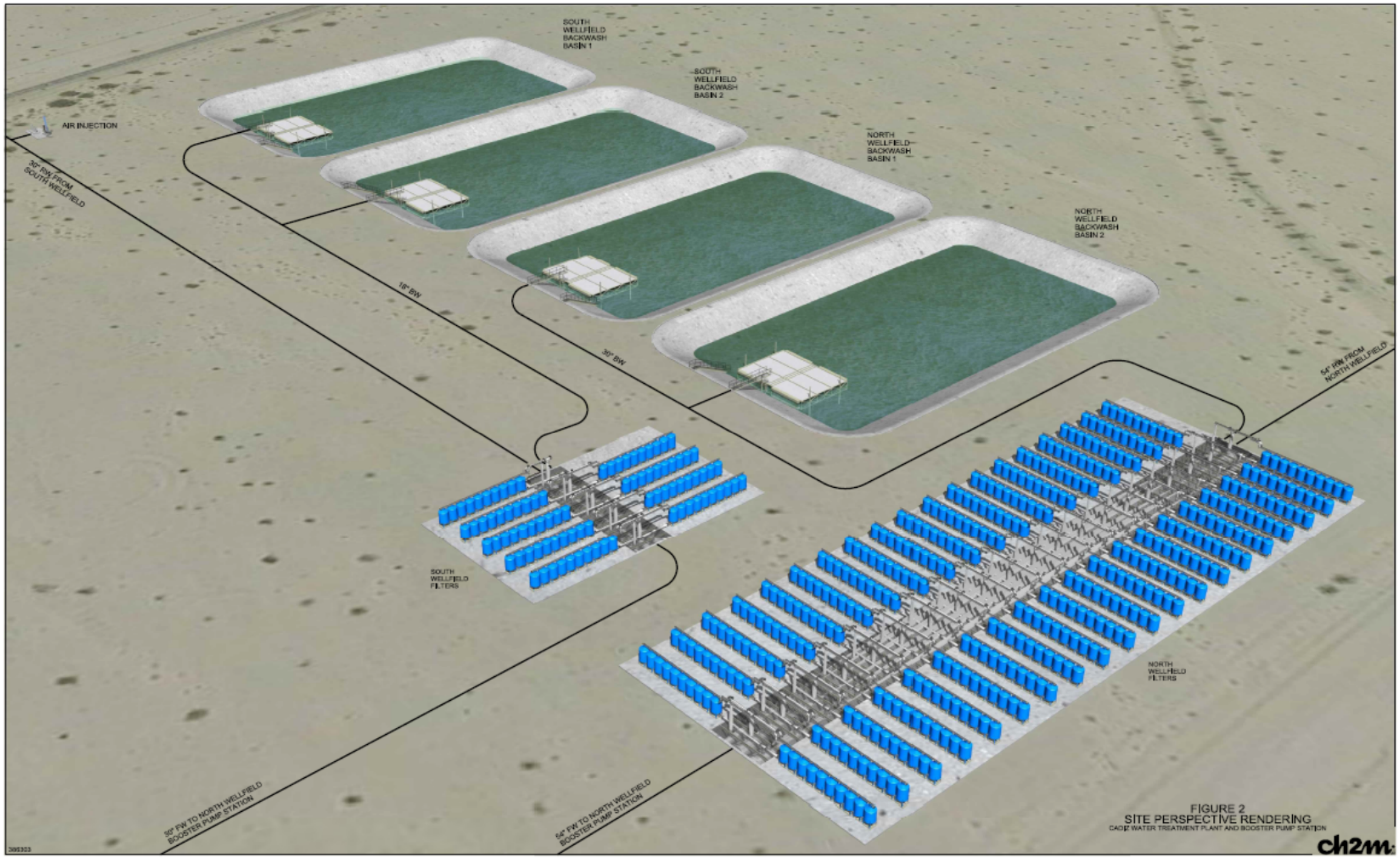


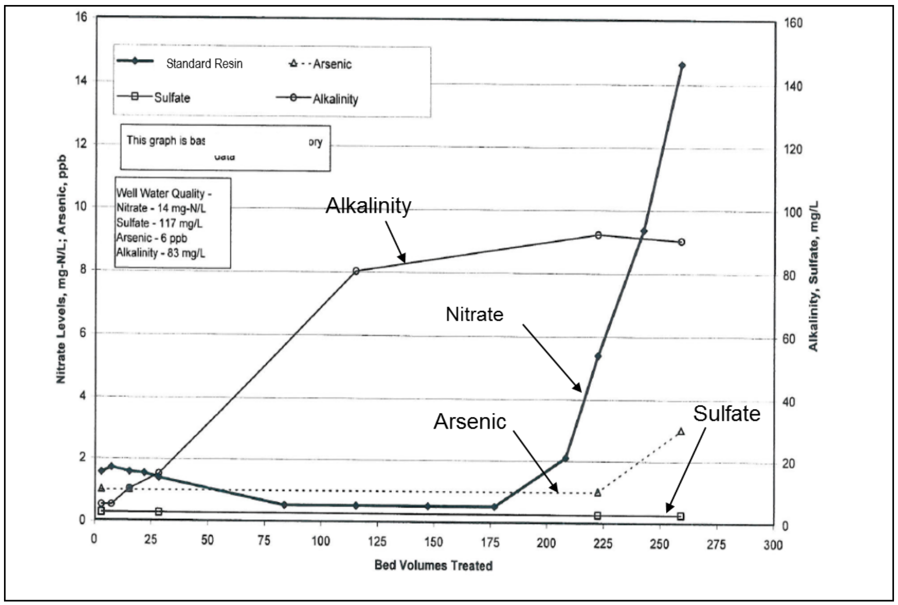
FIGURE 2
SITE PERSPECTIVE RENDERING
CADIZ WATER TREATMENT PLANT AND BOOSTER PUMP STATION

FILENAME: Cadiz_Figure2_386303.dgn PLOT DATE: 20170403 PLOT TIME: 9:40:00 AM

Arsenic Removal

- Reverse Osmosis
- Activated Alumina
- Ion Exchange
- Ferric Coagulation
- Iron-Based Media

Technology	Benefits	Drawbacks
Conventional filtration	•Common technology Effective, especially when arsenic pre-oxidized and pH kept below 8	•Performance declines above pH 8Arsenic should be pre-oxidized •High coagulant doses sometimes required. •Alkalinity addition may be needed for soft waters and high coagulant doses.
Reverse osmosis membrane filtration	•Removal of As(III) and As(V) •Inorganic, microbial, and organic removal also achieved	•Low recovery and flux rates are typical •Pretreatment and posttreatment required
Nanofiltration	•Removal of As(V) •Microbial and organic removal also achieved •Removal of calcium and magnesium may be achieved	•Sensitivity to water quality •Low recovery and flux rates are typical •Pretreatment and posttreatment required •May not be effective for As(III)
Ultrafiltration	•Flux and recovery rates higher than with reverse osmosis or nanofiltration •Microbial removal achieved •Waste stream can often be sent to wastewater treatment plant	•Removal of particulate As only, unless pretreatment with a coagulant is needed for removal •Preoxidation and pH adjustment may be needed
Coagulation/microfiltration	•Highest flux and recovery rates of membrane processes •Some microbial removal achieved •Waste stream can often be sent to wastewater treatment plant	•Pretreatment with a coagulant is needed for removal •Preoxidation and pH adjustment may be needed
Activated alumina	•Less sensitive to water quality than ion exchange •Longer run times than ion exchange	•pH adjustment often needed •Aluminum levels may increase in finished water •Hazardous chemicals needed for regeneration •Residuals handling is difficult with concentrated high-pH liquid stream
Ion exchange (anion exchange)	•Works better at higher pH levels than activated alumina •Nitrate removal can also be achieved	•Sulfate levels may reduce run times •Higher arsenic levels may leach from resin near end of run •Requires regeneration and handling of concentrated brine solution
Iron-based sorbents	•Arsenic in backwash water is usually very low •Relatively easy disposal of solids •Some adsorbents have a fairly high sorption capacity	•Periodic media replacement required •Cost and length of media use before replacement is needed is dependent on water quality •Capacity decreases with increasing pH
Titanium-based sorbents	•Arsenic in backwash water is usually very low •Relatively easy disposal of solids •Some adsorbents have a fairly high sorption capacity •Works over wide range of pH	•Periodic media replacement required •Cost and length of media use before replacement is needed is dependent on water quality
Lime Softening	•Effective removal at pH above 11. •Coagulants can be added to aid co-precipitation.	•High concentration of solids produced •Some systems can require significant operational oversight


Standard Resin
Arsenic
Sulfate
Alkalinity
Well Water Quality -
Nitrate - 14 mg-N/L
Sulfate - 117 mg/L
Arsenic - 6 ppb
Alkalinity - 83 mg/L
Alkalinity
Nitrate
Arsenic
Sulfate
Nitrate Levels, mg-N/L; Arsenic, ppb
Alkalinity, Sulfate, mg/L
Bed Volumes Treated
0
25
50
75
100
125
150
175
200
225
250
275
300
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160


02/03/2011 15:34

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Granular Ferric Hydroxide for Arsenic Removal

- Golden State Water Century Plant
  - Manganese 0.1 mg/L
  - Arsenic 0.03 mg/L
  - Discharge to Stormwater

Operational: Multiple Sampling Ports
Distributions Water Quality: pH Adjustment in Future
Residuals Disposal: TCLP (California WET Test), Paint Filter Test

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RSSCT Column Preparation

- Crush full-scale media
- Sieve media – usually to 100x140 mesh
- Weigh crushed adsorbent and add to column
- Backwash column to remove fines
- Tap column to compress bed
- Place effluent tube above media elevation to prevent air entrainment
- Condition with DI water
- Start test

(Ref. Dr. Paul Westerhoff, Ariz. State Univ.)

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FIGURE 1: CHLORINE/ACID/FERRIC/CONTACT TANK

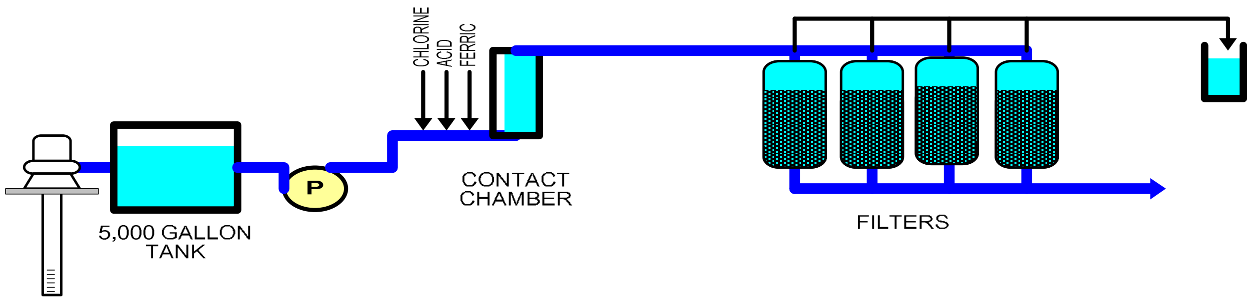
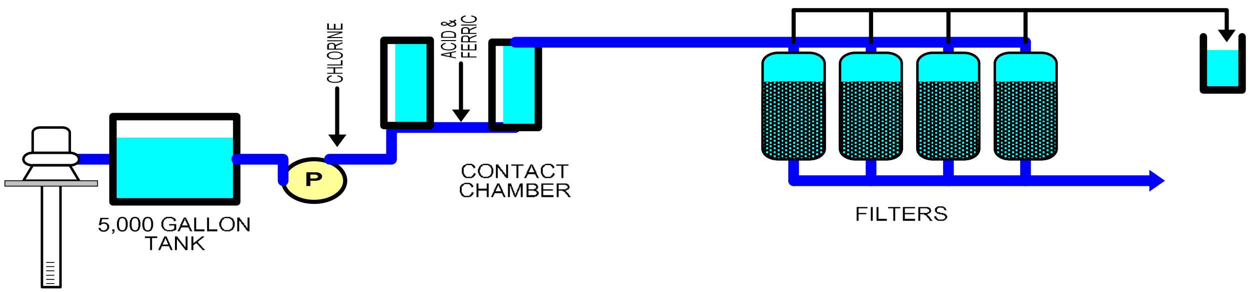


FIGURE 2: CHLORINE/CONTACT TANK/ACID/FERRIC/CONTACT TANK



Moving the Chlorine injection Location and adding Contact time optimized removal

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Questions?

Lee.odell@Jacobs.com

May 9, 2019

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