Feasibility of Water Treatment Technologies for Arsenic and Fluoride Removal

AWWA Water Quality Technology Conference
17 November 2004; Arsenic I

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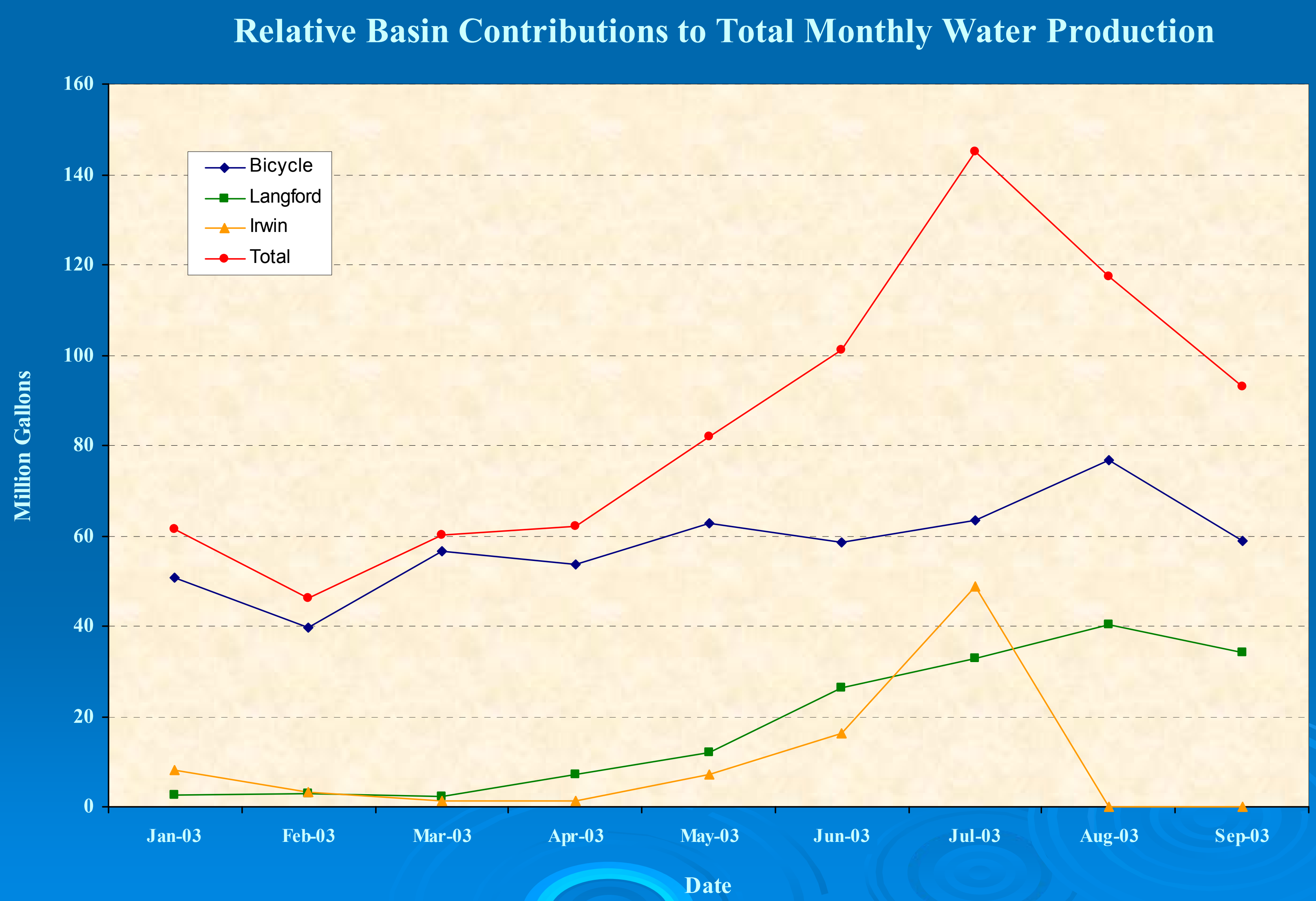
Overview

- Project Background
- Current Operations and “Consumptive Use”
- Contaminant Overviews
- Data Collection
- Treatment Alternative Analysis & Considerations
- Treatment Alternatives Screening
- Conclusions

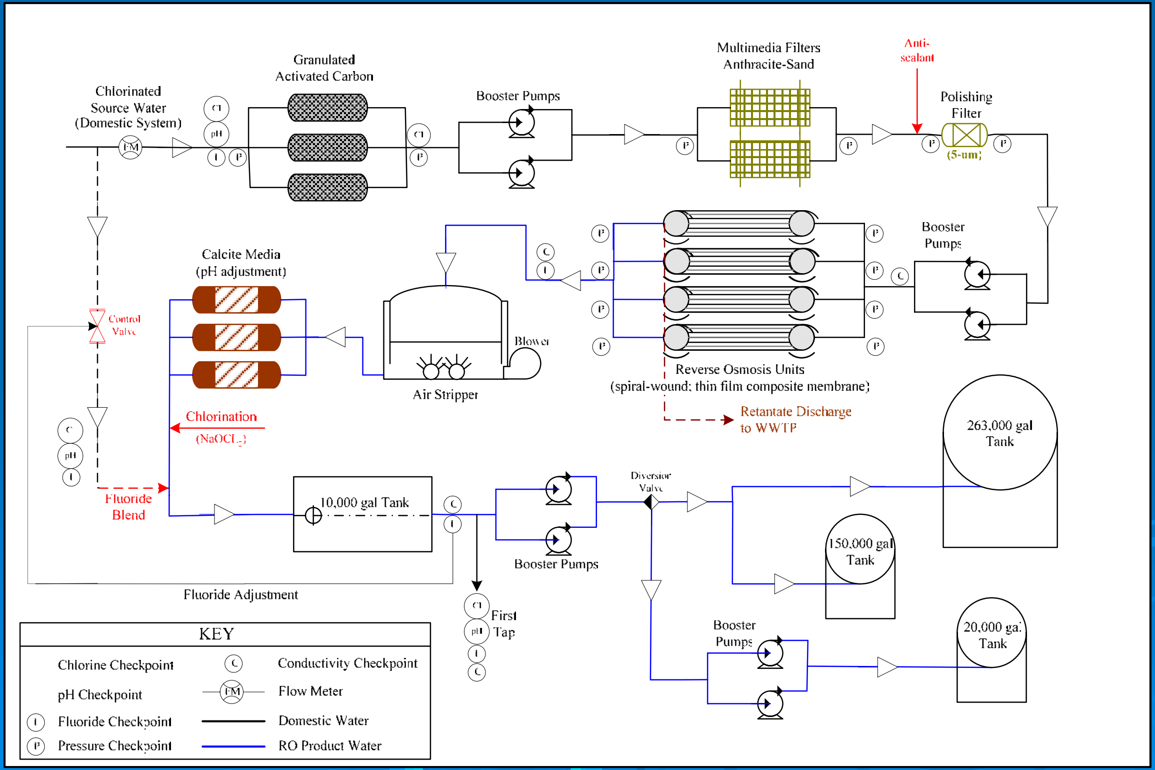
Project Background

- **Location**: Fort Irwin, CA, approximately 35 miles northeast of Barstow, California, in the north-central part of the Mojave Desert
- **Source Water**: 11 groundwater wells from three distinct geologic basins (Irwin, Bicycle, and Langford)
- **Water Demand**: Fort Irwin houses the Army's National Training Center, so water demand fluctuates due to troop rotations and seasonal irrigation
- **Source Water Contaminants of Concern**
  - **Arsenic (As)** > future MCL of 0.010 mg/L (January 2006)
  - **Fluoride (F)** > State MCL of 2 mg/L


Relative Basin Contributions to Total Monthly Water Production
160
140
120
100
80
60
40
20
0
Million Gallons
Bicycle
Langford
Irwin
Total
Jan-03
Feb-03
Mar-03
Apr-03
May-03
Jun-03
Jul-03
Aug-03
Sep-03
Date

Existing Operations - Two Systems?

- **Dual-line** (domestic and potable) water distribution system
  - Domestic Water: chlorinated groundwater at the wellhead (bathing, irrigation, toilet flushing, etc);
  - Potable Water: 0.15 MGD Reverse Osmosis (RO) plant for potable water



“Consumptive Use” Conundrum

- In defining a Public Water System in 1996 SDWA Amendments, EPA broadened the definition of “consumptive use” to more than just drinking, stating “…human consumption includes drinking, bathing, showering, cooking, dishwashing, and maintaining oral hygiene”

- **All** consumptive use water, not just the RO-treated potable portion, would need to meet SDWA requirements, including compliance with arsenic and fluoride MCLs

Treatment Requirements

- Co-removal treatment technology for As and F
  - Arsenic Rule, January 2001, revised arsenic MCL from 50 µg/L to 10 µg/L, enforceable mid-January 2006
  - Fluoride MCL is 2 mg/L (CDHS; SDWA is 4 mg/L)
- WTP design flow will increase from 0.15 to 5.0 MGD and employ 1-line distribution system
- Design/construction of a new, full-scale WTP
  - First priority: water conservation
  - Consider waste flows

Contaminant Overviews

Contaminant Overview: Arsenic

- **Occurrence**
  - Common, naturally-occurring drinking water contaminant originating from arsenic-containing rocks and soil, transported to natural waters via erosion, dissolution and air emission
  - Man-made sources: mining and smelting operations; agricultural applications; and the use/disposal of industrial products
  - Arsenite, As(III); neutral surface charge vs. Arsenate, As(V), negative surface charge
- **Health Effects** - Both cancerous and non-cancerous effects
  - Class A human carcinogen, with low arsenic exposure (< 0.05 mg/L) linked to cancer of the skin, liver, lung and bladder
  - Large arsenic doses (above 60 mg/L) can cause death;

    lower doses (0.30-30 mg/L) may cause stomach and intestinal irritation and nervous system disorders

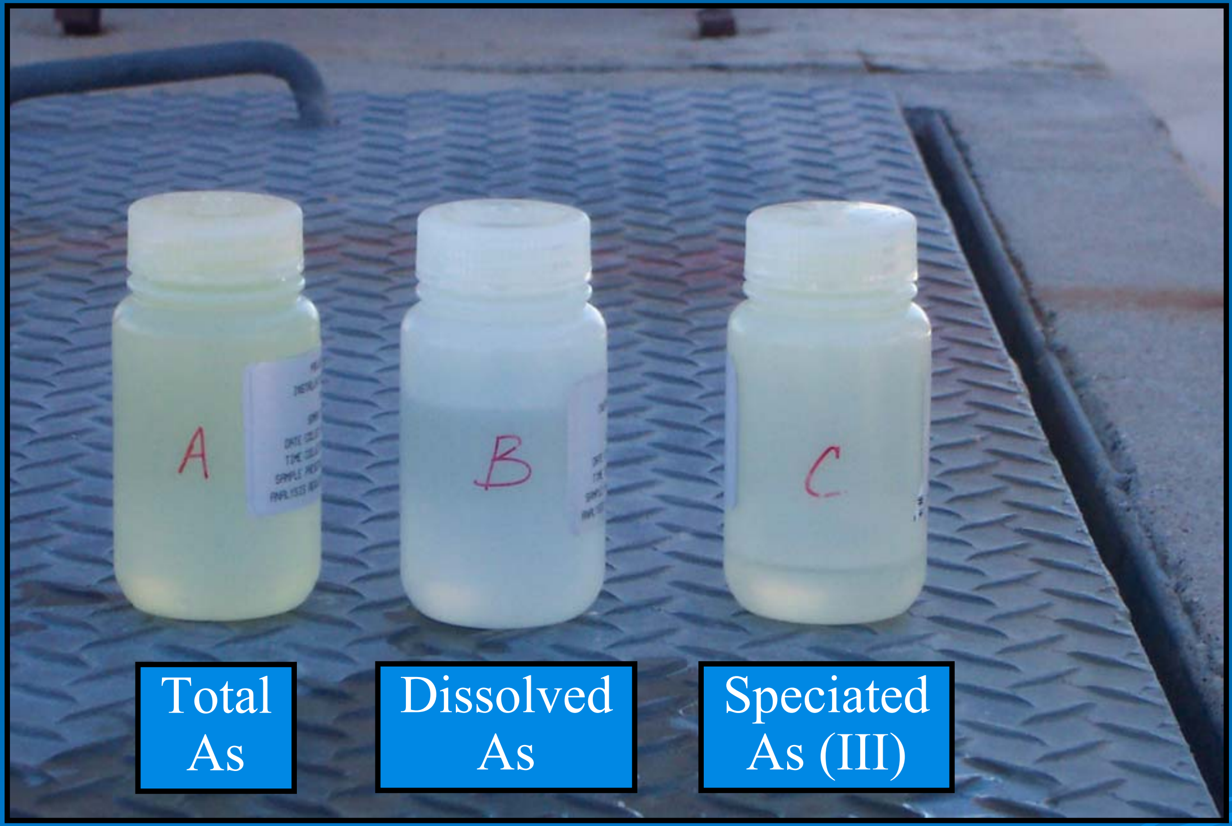
Contaminant Overview: Fluoride

- **Occurrence**
  - contained in minerals, fluorspar (fluorite) and apatite (calcium fluorides) and released as fluoride ions when contacted with GW, thus fluoride is found naturally in all waters
  - Typical GW concentrations range from trace to greater than 5 mg/L, with deeper GW generally having higher fluoride concentrations
- **Health Effects**
  - Drinking water fluoride concentrations greater than 4 mg/L can cause bone disease in adults and tooth mottling (discoloring) in children
  - Moderate fluoride levels (0.7 to 1.2 mg/L, temperature-dependent) in drinking water are beneficial to children during the time they are developing permanent teeth

Data Collection

Onsite Data Collection

- Supplement existing source water data
- Source water characteristics significantly affect treatment alternative selection (pH, TDS, sulfate, silica)
- Field Arsenic Speciation Kits- only reliable way to determine source water arsenic forms
  - Particulate versus dissolved (soluble)
  - Reduced [As(III)] versus oxidized [As(V)]


A
B
C
Total As
Dissolved As
Speciated As (III)

Source Water Characterization Results

Source Water Aquifer	Parameter			
	Fluoride (mg/L)	Arsenic (µg/L)		
		Total	As(III)	As(V)
	Range	Range		
Bicycle Lake	1.1 to 4.5	< 2.0 to 30.3	<10%	≥ 90%
Langford Lake	4.4 to 9.9	7.9 to 15.8	< 1%	≥ 99%
Irwin	8.0 to 10.6	32.2 to 40.1	< 5%	≥ 95%
California State MCL	2.0	Current: 50 µg/L; Future: 10 µg/L		

Source Water Aquifer	Parameter (mg/L)			
	pH	Sulfate	TDS	Silica
Bicycle Lake	7.6 to 7.9	110 to 130	590 to 650	60 to 125
Langford Lake	8.2 to 8.5	105 to 150	480 to 560	25 to 35
Irwin	8.1	132	130	85

Treatment Alternative Analysis & Considerations

Water Quality Treatment Goals

Constituent	Water Quality Goal (mg/L, unless noted)		
Primary MCL			
Arsenic[1]	0.0080	--	--
Fluoride[1]	1.6	--	--
Nitrate[1]	8.0 (as N)		
Secondary MCL			
pH	6.5-8.5	--	--
Color	15 units	--	--
Turbidity	5 units	--	--
Odor - Threshold	3 units	--	--
Iron	0.3	--	--
Manganese	0.05	--	--
Alkalinity	> 30 mg/L $CaCO_3$	--	--
Corrosivity	0 to 0.05 LSI	--	--
	Recommended	**Upper[2]**	**Short Term[2]**
TDS	500	1,000	1,500
Sulfate	250	500	600
Chloride	250	500	600

1 - design for 80% of the MCL;

2 - Per California regulations.

Treatment Avoidance & Blending

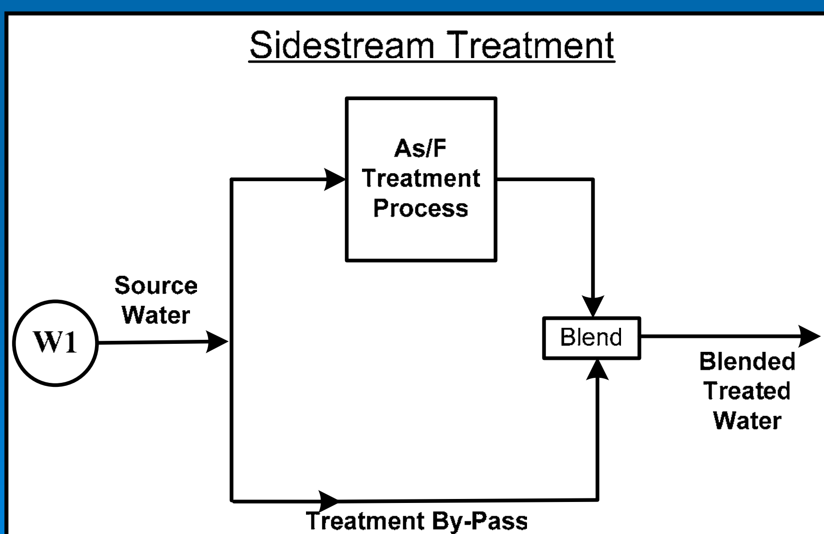
- Non-treatment: contributions of targeted source water wells are either eliminated or combined such that the product water entering the distribution system meets the arsenic and fluoride MCLs

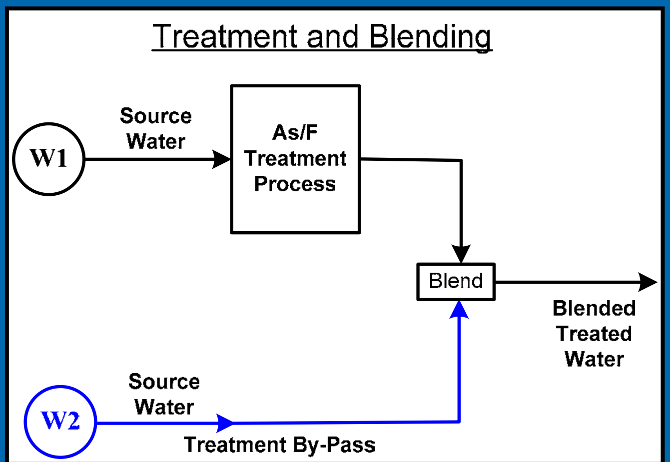
- Sidestream Treatment: treating only a portion of the source water, so that subsequent blending with the untreated portion produces finished water that meets arsenic and fluoride MCLs

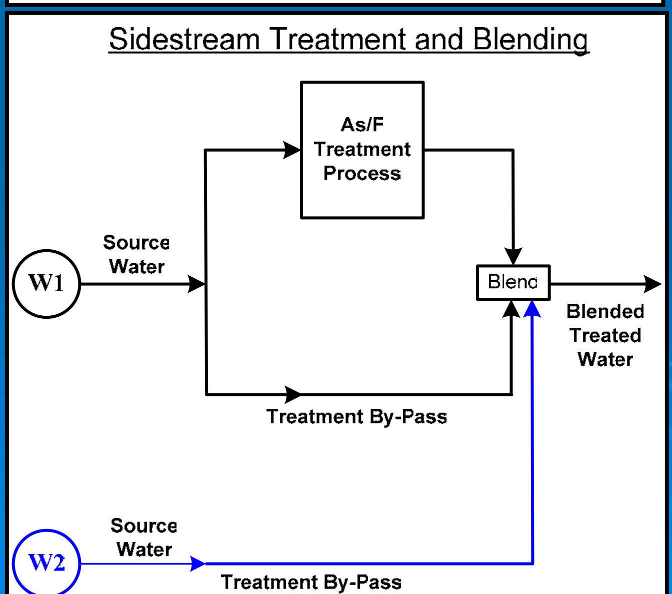
Blending Strategies

Mass Balance Equation

$$Q_{SS} = Q_1 \left(\frac{C_{As/F,1} - (1-\sigma) C_{MCL}}{\varepsilon C_{As/F,1}} \right)$$







Treatment Options

Best Available Technologies (BATs)

Arsenic	Fluoride
Activated Alumina (AA)	**AA**
Ion Exchange (IX)	**RO**
Reverse Osmosis (RO)	
Electrodialysis Reversal (EDR)	
Oxidation/Filtration	
Enhanced Coagulation/Filtration	
Enhanced Lime Softening	

Co-removal BATs	Removal Efficiency		Water Loss	Optimal Conditions	Operator Skill
	As	F			
Activated Alumina (AA)	95%	85-95%	1-2%	pH 5.5-8.3 (decreased efficiency at high pH); < 360 mg/L SO_4; < 1,000 mg/L TDS; < 250 mg/L Cl, < 0.5 mg/L Fe; < 0.05 mg/L Mn; < 4 mg/L TOC; < 30 mg/L Silica; < 0.3 NTU Turbidity;	Low
Reverse Osmosis (RO)	> 95%	85-95%	40-60%	< 30 mg/L silica for <15% water loss; (per RO manufacturers) No particulates.	Medium
Other Treatment Technologies	**Removal Efficiency**		**Water Loss**	**Optimal Conditions**	**Operator Skill**
	As	**F**			
Electrodialysis Reversal (EDR)	> 95%	85-95%[3]	20-30%	Treats most waters without preference; Process efficiency not affected by silica; Most economical for TDS of 3,000-5,000 mg/L;	Medium
Coagulation/ Micro-Filtration (C/MF)	90%	NS	5%	pH 5.5-8.5	High
Iron Based Sorbents	up to 98%	No	1-2%	pH 6-8.5 (decreased efficiency at high pH); < 1 mg/L PO_4; < 0.3 NTU Turbidity;	Low
Ion Exchange (IX)	95%	No	1-2%	pH 6.5-9 (decreased efficiency at high pH); < 50 mg/L SO_4; < 500 mg/L TDS; < 5 mg/L NO_3, < 0.3 NTU Turbidity;	High
Point of use/Point of entry Devices	95%	Vary	Vary	Scaled down versions of IX, AA, RO processes.	Low

Adsorption Considerations

- Competing Ions
  - Activated Alumina

$$OH^- > H_2AsO_4^- > Si(OH)_3O^- > F^- > HSeO_3^- > TOC > SO_4^{2-} > H_3AsO_3$$

  - Ion Exchange (IX)

$$SO_4^- > HAsO_4^{2-} > NO^{3-}, CO_3^{2-} > NO^{2-} > Cl^-$$

- IX is not a BAT for F removal; and SO_4^- over 50 mg/L precludes IX as an economically viable technology (all source water > 100 mg/L sulfate)

Membrane Considerations

- Silica concentrations of 75 mg/L will limit RO water recovery to about 60%, per manufacturer experience. Source water varies from 25-125 mg/L silica
- Pretreatment for silica removal may be needed prior to RO (dependent on pilot-scale testing results).
- EDR, which uses electrical current, instead of pressure, to remove ionic contaminants is not affected by silica concentrations

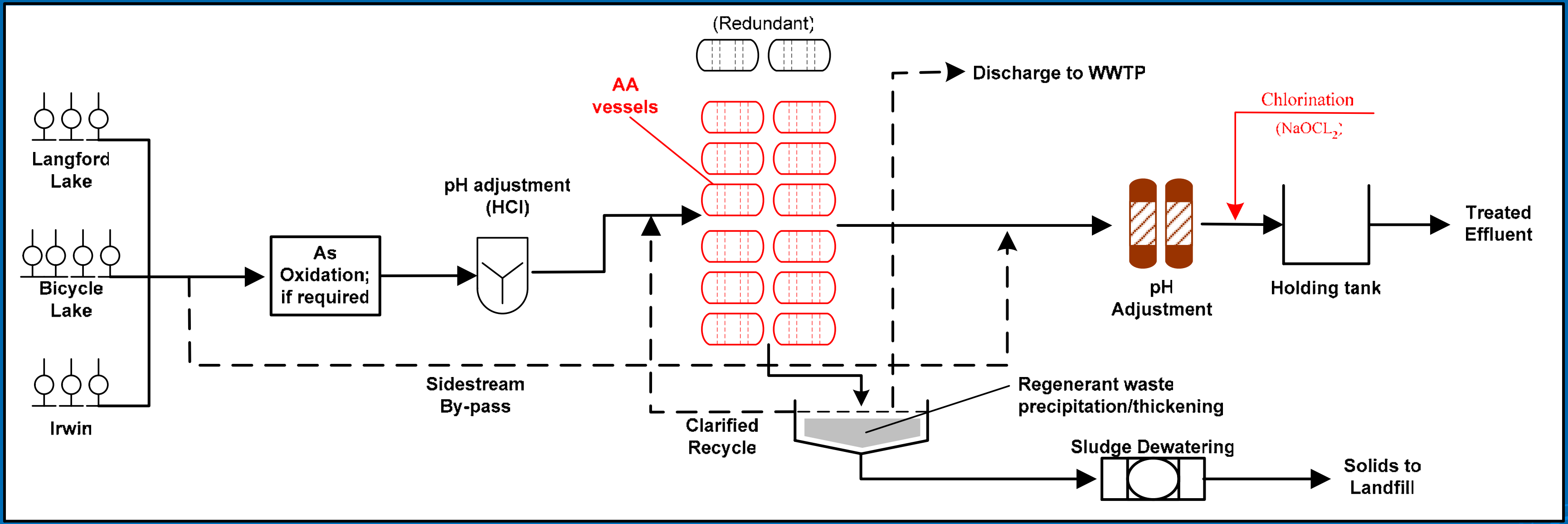
Waste Stream Considerations

AA - acid (pH adjustment) and caustic (media regeneration)

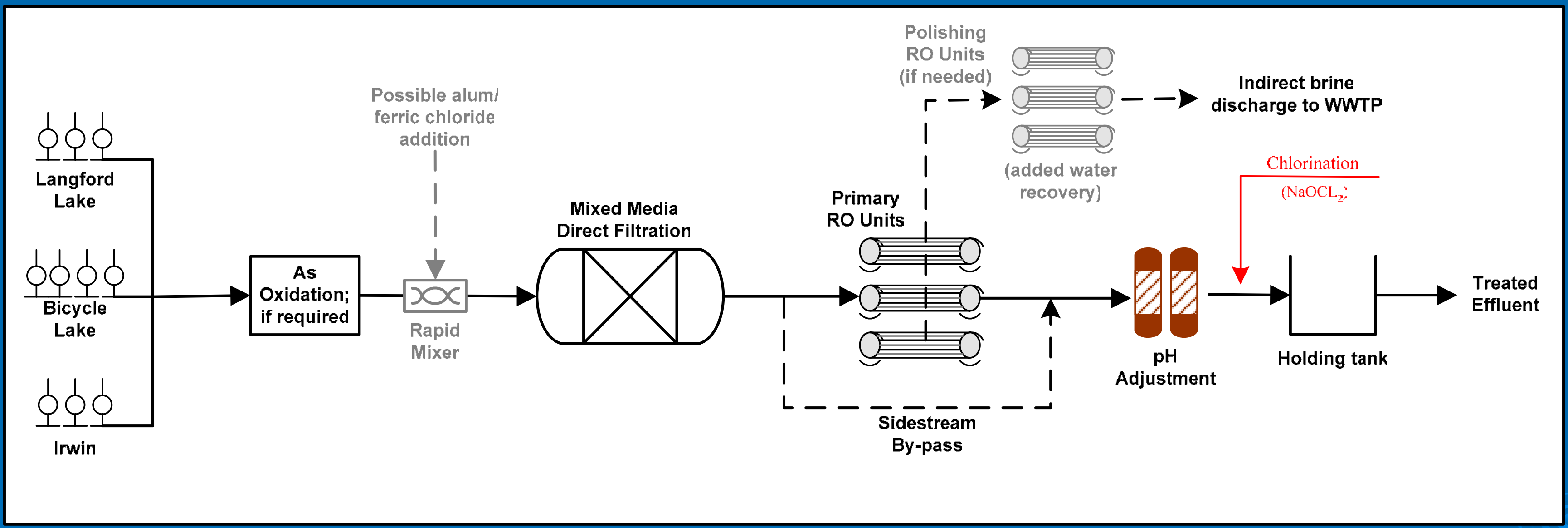
RO/EDR - Concentrated brine discharge

- Disposal Options
  - Direct discharge to evaporation ponds (100% water loss)
  - Indirect discharge to WWTP (partial GW recharge)
  - Vapor compression unit – near zero discharge, but $$$
- Sludge Criteria for Landfill Disposal
  - Sludge must have no free liquids - Paint Filter Test
  - Final sludge/spent media must be non-hazardous for landfill
  - EPA has TCLP; CA has WET (F salts)

AA Treatment Train



RO/EDR Treatment Train



Cost

TREATMENT ALTERNATIVE	COST ($) Capital	O&M/yr
ALTERNATIVE #1: STATUS QUO - Maintain current operations, including separate domestic and potable water systems.	0	155,000
ALTERNATIVE #2: ACTIVATED ALUMINA - Construct AA columns at central location; - Pre and post treatment (pH/filtration) likely needed; - Blending used to decrease hydraulic loading; - Periodic regeneration/disposal of spent media.	**4.3M**	**455,000**
ALTERNATIVE #3: REVERSE OSMOSIS/ELECTRODIALYSIS - Construct membrane units at central location; - Pre and post treatment (filtration, conditioning chemicals, pH/alkalinity adjustment), as needed; - Blending used to decrease hydraulic loading; - Multiple pass design may minimize water loss.	RO 15.0M EDR 13.0M	RO 1.35M EDR 950,000

*Note: Site-specific cost factors may increase the AA capital cost to approximately $7.6M, per Fort Irwin Facilities Personnel

Treatment Alternatives Screening

Screening Criteria

- Each treatment alternative was screened against seven relevant criteria
- Except for cost, all criteria were qualitative, and rated on a scale of 1 to 7 (7 being best, and 1 being worst)
- Criteria scores were then summed to derive an overall alternatives ranking, with the highest scoring alternative being the preferred choice
- Criteria were weighted (2:1) toward regulatory compliance, water conservation and cost

		Treatment Alternatives		
Criteria	Wght	#1 STATUS QUO	#2 AA ADSORPTION	#3 RO/ EDR
Regulatory Compliance	.2	1 (0.2)	6 (1.2)	7 (1.4)
Water Conservation	.2	6 (1.2)	6 (1.2)	2 (0.4)
Cost	.2	1* (0.2)	6 (1.2)	3 (0.6)
Implementation	.1	1 (0.1)	5 (0.5)	4 (0.4)
Production Capacity	.1	1 (0.1)	5 (0.5)	4 (0.4)
Public Perception and Acceptance	.1	1 (0.1)	5 (0.5)	5 (0.5)
Occupational & Environmental	.1	4 (0.4)	3 (0.3)	3 (0.3)
Raw Score	**49**	**15**	**36**	**28**
Weighted Score	**(7)**	**(2.3)**	**(5.4)**	**(4.0)**

* - based on potential non-compliance penalties

Search for Comparable Facility

- **29 Palms AA WTP - 3 MGD Design flow**
  - Located in the Hi-Desert Water District in Yucca Valley, California
  - GW source concentrations: As: < 5 µg/L;
    F: 5-7 mg/L; 250 mg/L of TDS
  - Blending: bypass 25% of the raw water
  - Provides excellent treatment, endorsed by operators
  - Novel precipitation/spray irrigation system (salt brush)
- **Pilot-plant studies favored AA over RO/EDR**

Conclusions

Treatment Technology Considerations

- Consider:
  - Source water characteristics: As forms, pH, competing ions, silica, etc.
  - Non-treatment options
  - BATs; also look for comparable facilities
  - Waste flows and sludge disposal
- For Fort Irwin:
  - AA was the recommended treatment technology
  - Conduct pilot-plant studies to verify effectiveness

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- Mr. Art Lundquist, USACHPPM

Questions?

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