Introduction to Arsenic Mitigation Techniques and the Arsenic Mitigation Checklist

List of Acronyms and Abbreviations

- Pages xiv - xviii

Mitigation Checklist

(pages i – iii)

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan
11. Implement the strategy
12. Monitor at entry point

3. Non-Treatment Options

- Alternative Source
- Blending
- Seasonal Use
- Geological solutions

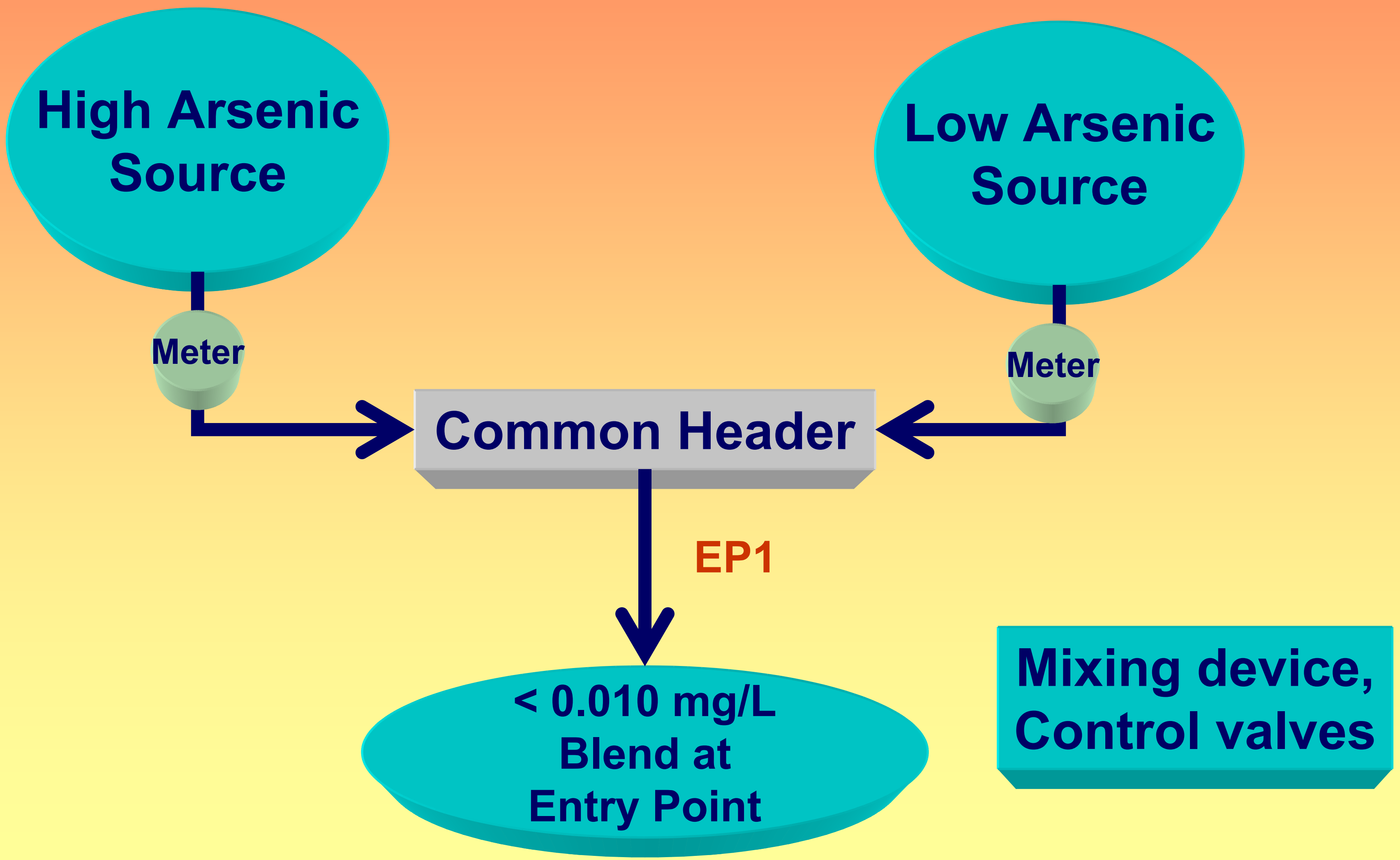
Alternative Source(s)

- Abandon high arsenic source(s)
- Use sources that meet standards

Sometimes the available
low arsenic sources
have a different set of problems.

- e.g., Total dissolved solids

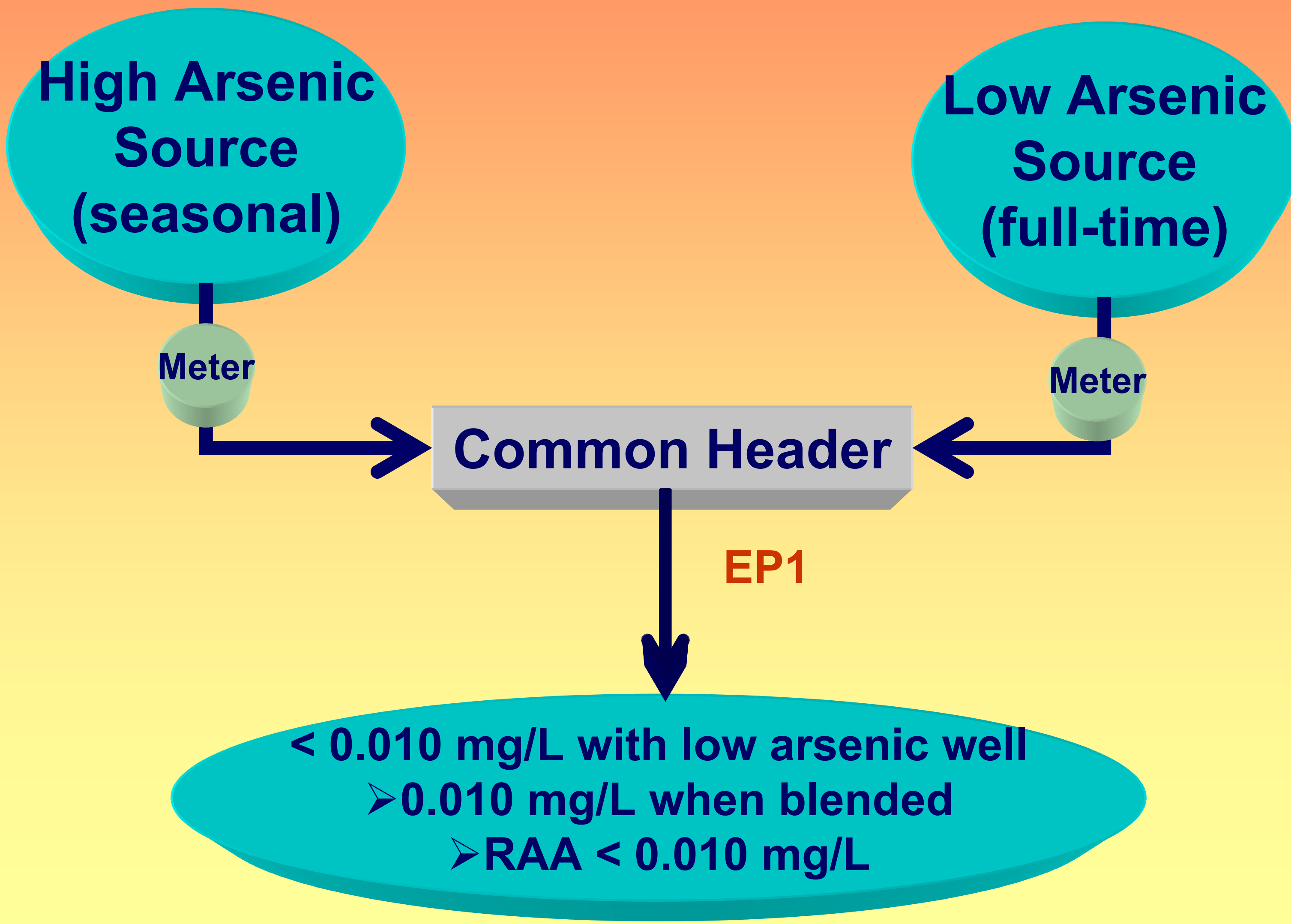
Blending



High Arsenic Source
Low Arsenic Source
Meter
Meter
Common Header
EP1
< 0.010 mg/L Blend at Entry Point
Mixing device, Control valves

Seasonal Use

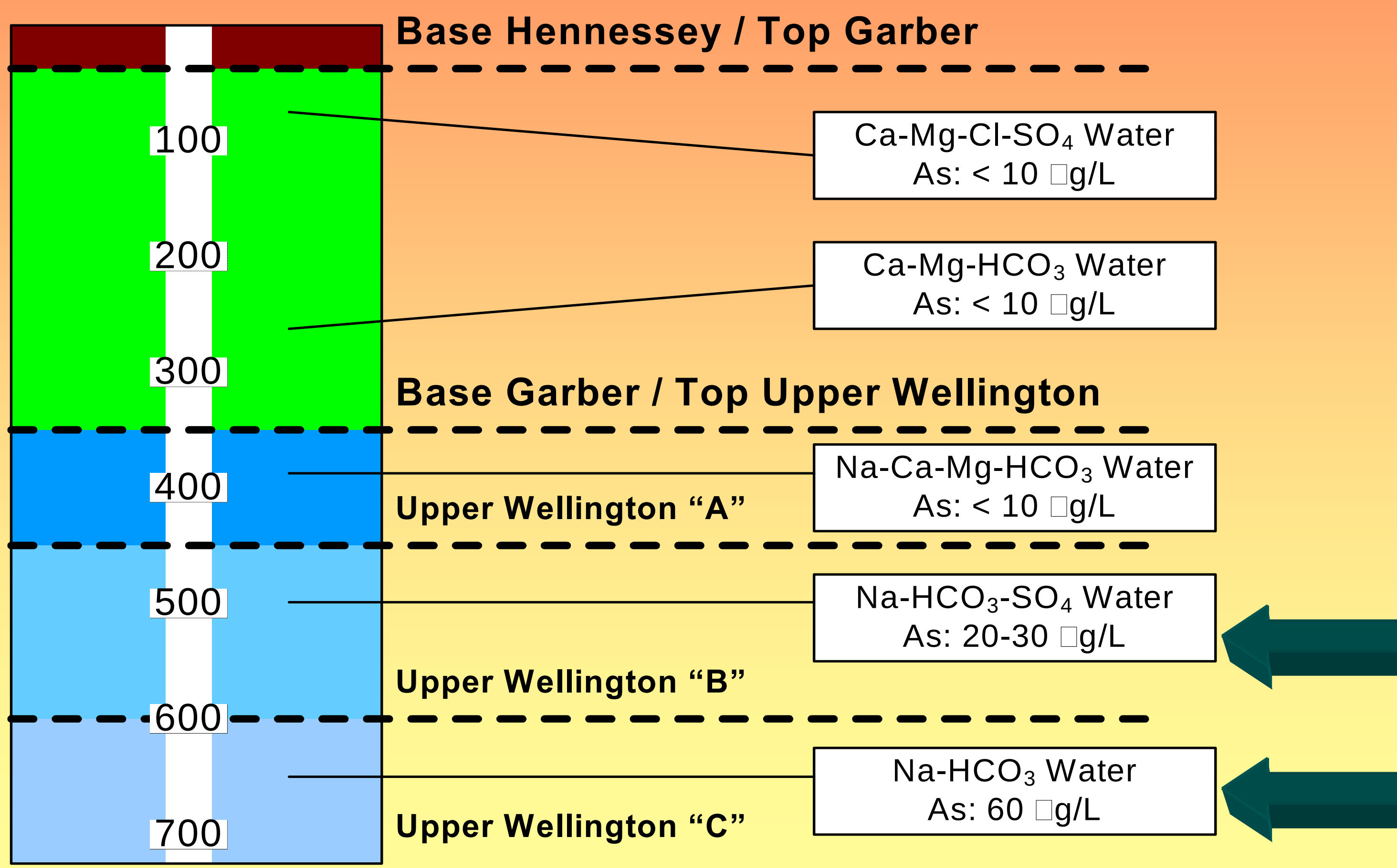
(Check With the State!)



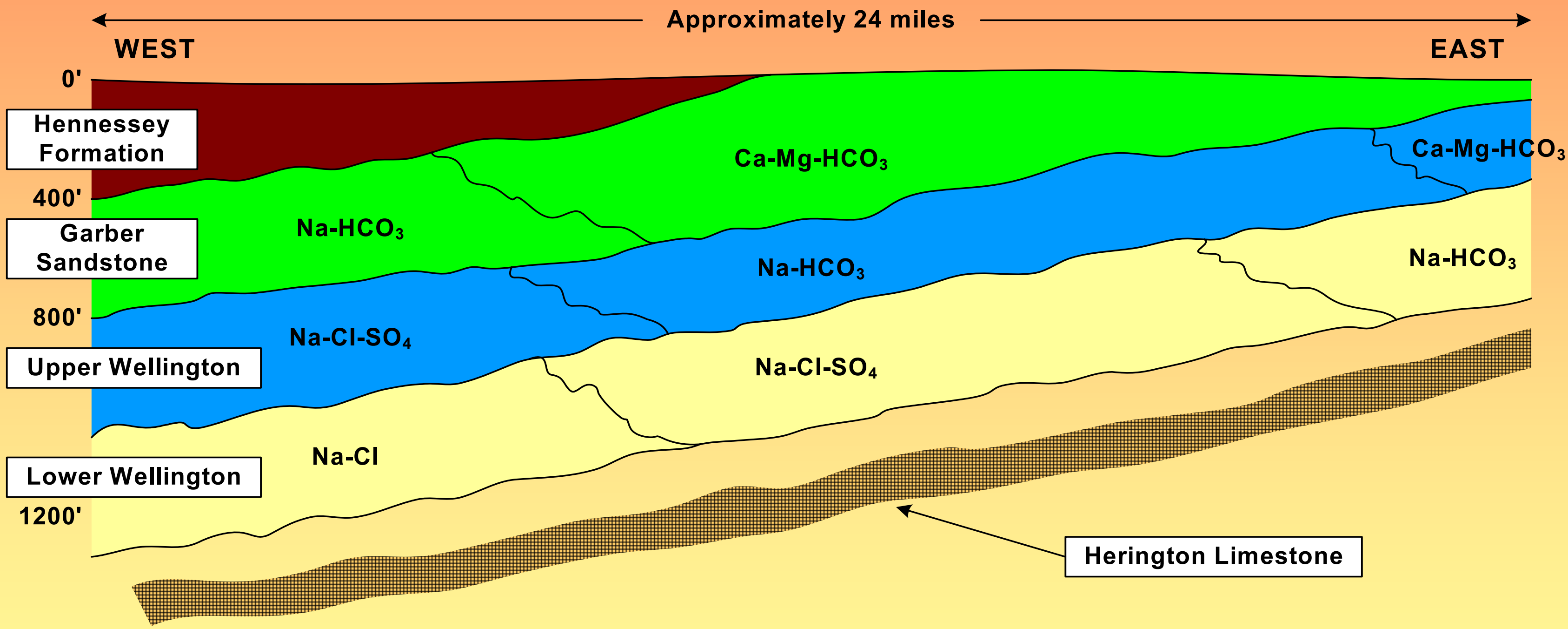
Geological Solutions

- Where arsenic concentrations vary significantly (location and/or depth)
  - Rehab existing wells
  - Drill new wells

Relationship Between Water Type & Stratigraphy



Regional Garber-Wellington Model
Showing General Water Types & Geology



More opportunity for high production, low arsenic wells as you move to the west.

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. **Measure water quality parameters**
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan
11. Implement the strategy
12. Monitor at entry point

4. Raw Water Testing

- Key parameters
  - Total arsenic
    - Arsenite
    - Arsenate
  - Chloride
  - Fluoride
  - Iron
  - Manganese
  - Nitrate/Nitrite
  - Orthophosphate
  - pH
  - Silica
  - Sulfate
  - Total Dissolved Solids (TDS)
  - Total Organic Carbon (TOC)
  - Temperature

- Other parameters
  - Alkalinity
  - Aluminum
  - Calcium
  - Magnesium
  - Turbidity
  - Hardness

pH
Alkalinity
Turbidity
Temperature

Raw Water Testing

- Look for:
  - Interfering ions
    - Some compete with arsenic
    - Some plug media and/or cause aesthetic problems (e.g., iron and manganese)
  - Other contaminants you may want to remove simultaneously
    - Nitrate
    - TDS
    - Iron

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. **Determine treatment evaluation criteria**
6. **Select a mitigation strategy**
7. **Estimate capital and O & M costs**
8. **Evaluate design considerations**
9. **Pilot test**
10. **Develop construction cost estimates and plan**
11. **Implement the strategy**
12. **Monitor at entry point**

5. Treatment Evaluation Criteria

- What are the existing treatment processes?
- Targeted finished water arsenic concentration?
- Is a POTW available?
- Is land available? What is the cost?
- What level of operator expertise is available?
- How much water loss can we afford?
- What capacity (flowrate) do we have to design for?
- Are there additional or more stringent requirements of the State?
  - These might impact selection of technology

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. **Select a mitigation strategy**
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan
11. Implement the strategy
12. Monitor at entry point

But First!

Arsenic

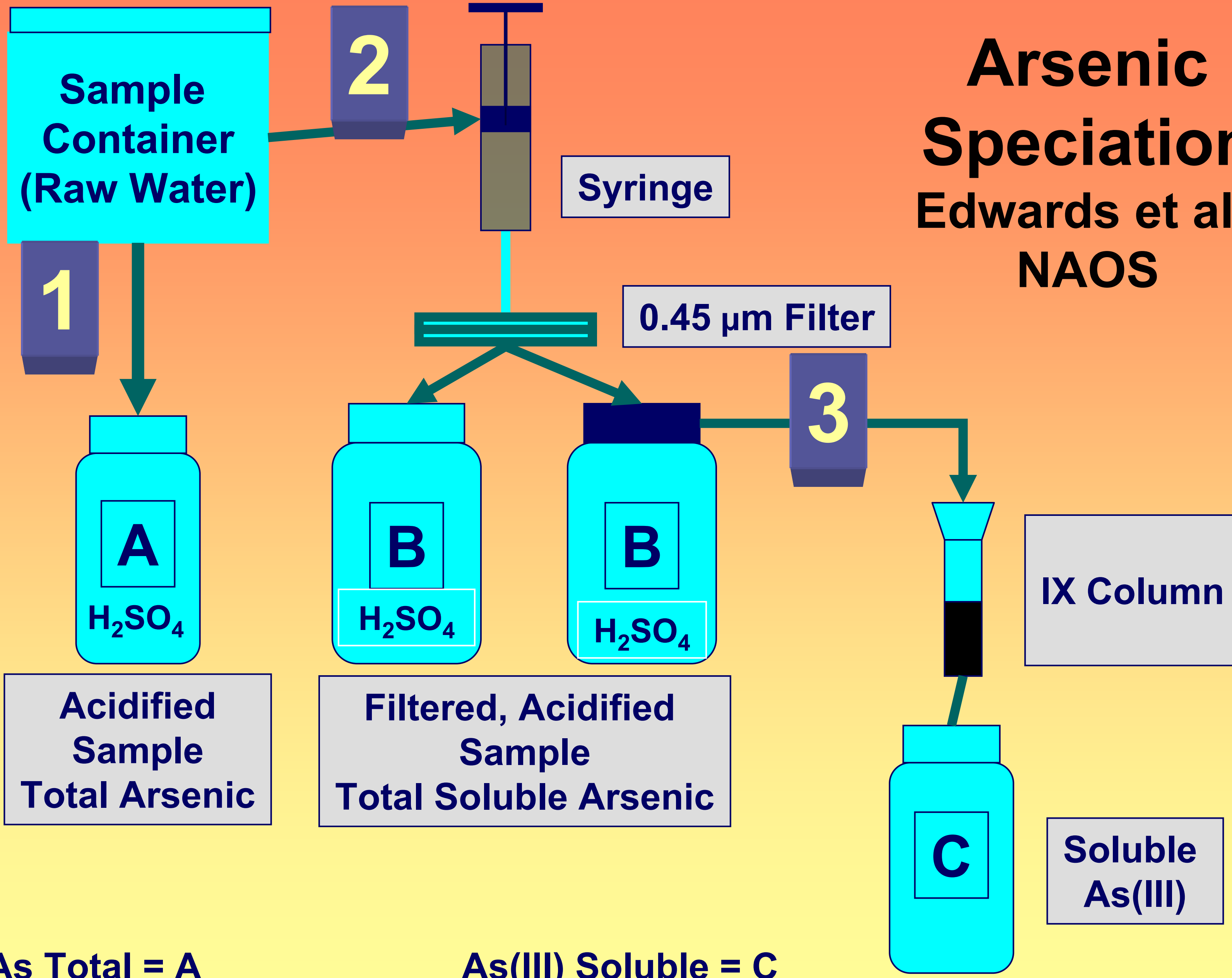
- Chemistry of Treatment
- Oxidation
- Residuals management

Arsenic Chemistry

- Found in water in two oxidation states
  - Arsenite (trivalent As III)
    - Reduced
    - Nonionic at natural pH
    - Difficult to remove
  - Arsenate (pentavalent As V)
    - Oxidized
    - Ionic at natural pH
    - Easier to remove

Arsenic Speciation

Edwards et al., NAOS



As Total = A
As Soluble = B
As Particulate = (A-B)*

As(III) Soluble = C
As(V) Soluble = B-C

For Practical Purposes….

- Plan on oxidation by chlorination
  - Virtually all technologies remove arsenic V better than arsenic III
  - States may require disinfection
- Consider the Ground Water Rule
  - Many common technologies are likely to provide adequate CT

Oxidation is First Step

Effective	Ineffective
Chlorine	Aeration
$KMnO_4$	Chlorine Dioxide
Ozone	Monochloramines
Solid Phase (Filox R™)	

Oxidation Processes (Chlorine)

- Chlorine
  - Pros
    - Low cost
    - Disinfectant
    - MnO_2 media regenerant
    - <1 minute for oxidation
  - Cons
    - DBPs
    - Handling and storage

Oxidation Processes (Permanganate)

- Permanganate
  - Pros
    - Un-reactive with membranes
    - No regulated DBPs
    - MnO_2 regenerant
    - < 1 min. to oxidize
  - Cons
    - Relatively costly
    - Not disinfectant
    - Formation of MnO_2 particles
    - Pink water
    - Difficult to handle

Oxidation Processes (Ozone)

- **Ozone**
  - Pros
    - On-site generation
    - Primary disinfectant
    - < 1 minute to oxidize
  - Cons
    - Sulfide and TOC interference
    - Not a secondary disinfectant
    - DBPs

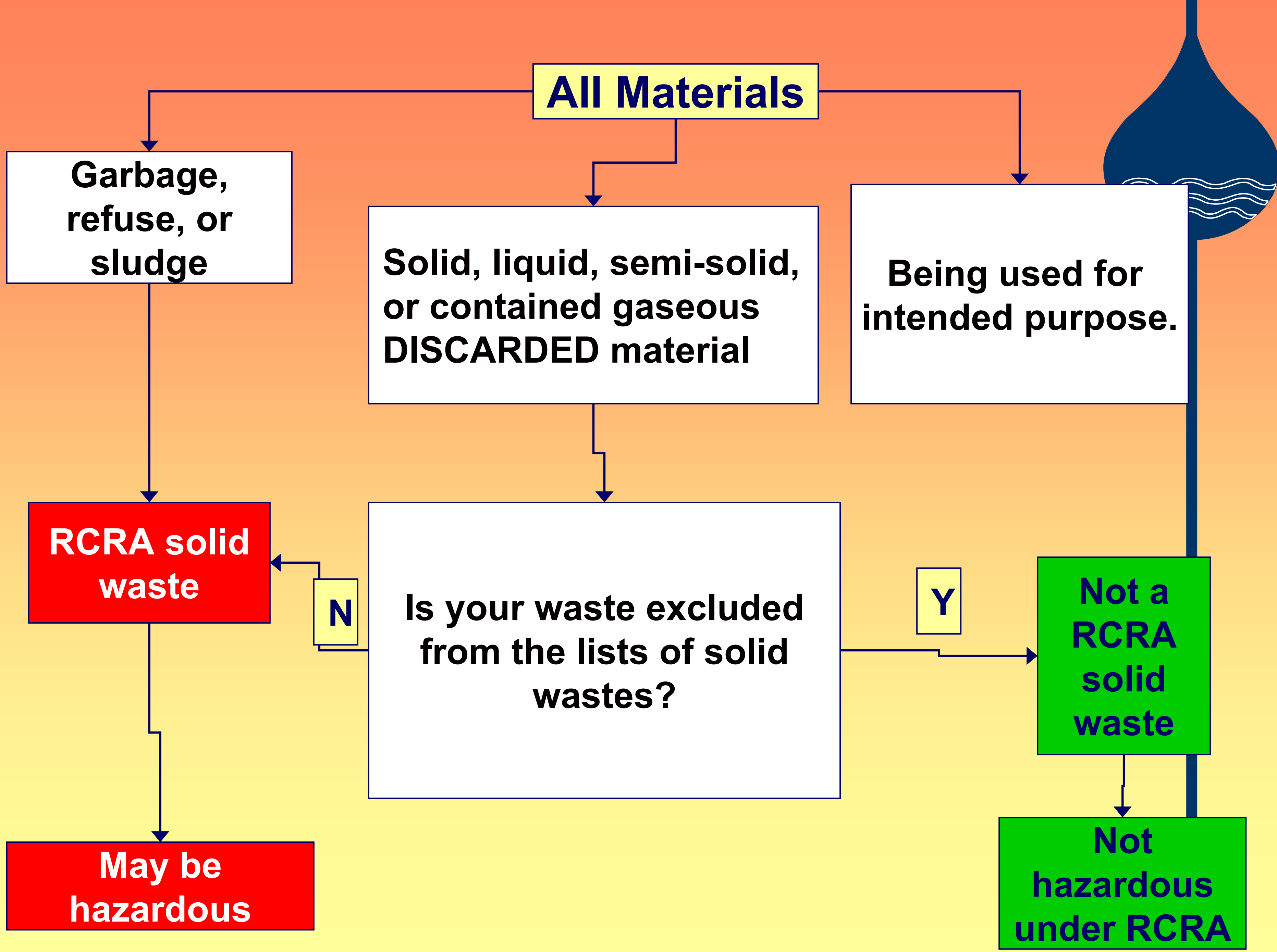
Residuals Management

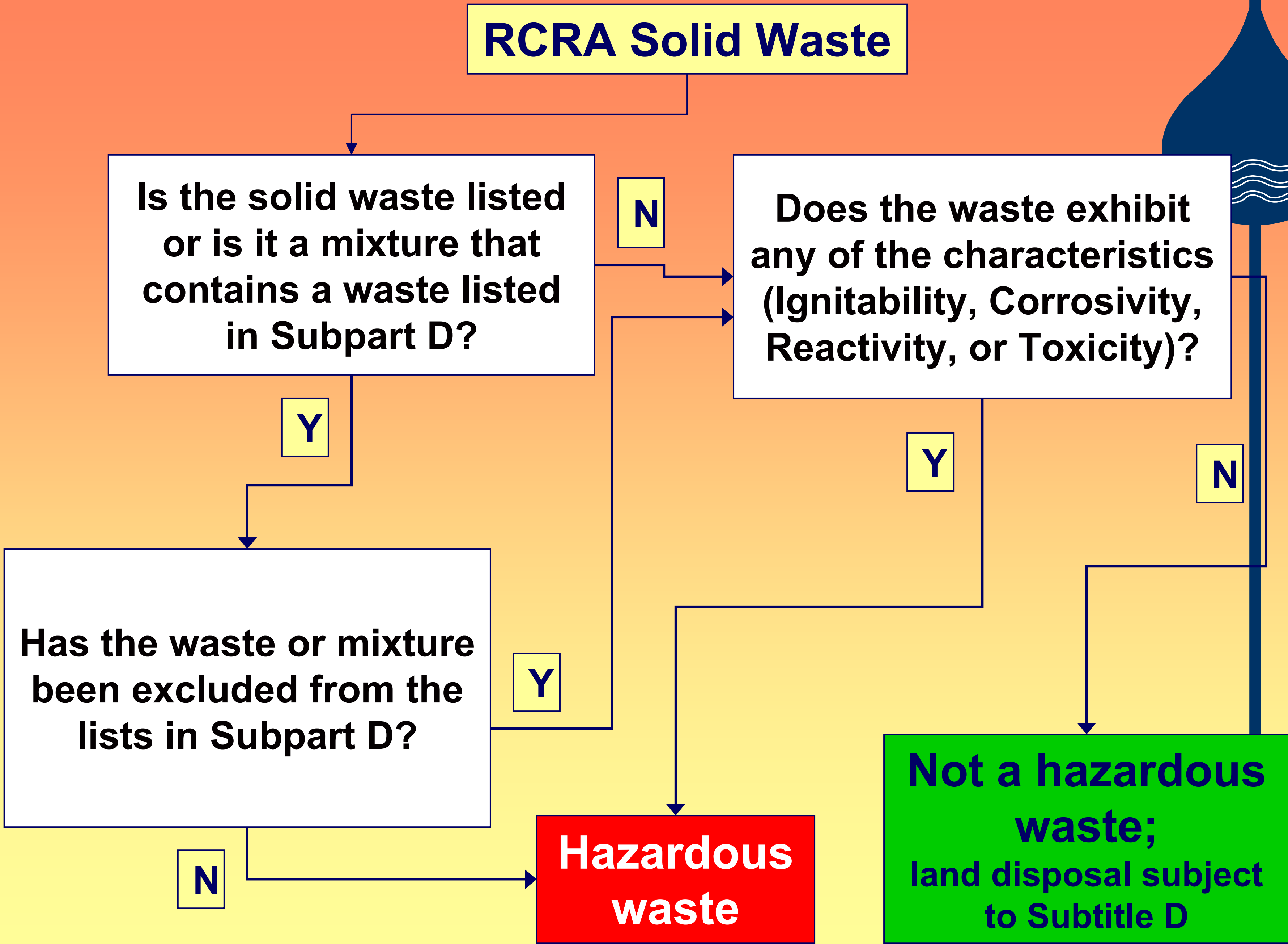
Terms of the Trade

- RCRA – **Resource Conservation and Recovery Act**
- OSHA – **Occupational Safety and Health Act**
- TCLP – **Toxicity Characteristic Leaching Procedure**
- TBLL – **Technically Based Local Limits**
- TTLC – **Total Threshold Limit Concentration**
- WET – **Waste Extraction Test**
  - STLC **–Soluble Threshold Limit Concentration**

RCRA

- Subtitle C – Hazardous Waste Management
  - **40CFR Part 261 – Identification and Listing of Hazardous Waste**
    - **Subpart C – Characteristics of Hazardous Waste**
    - **Subpart D – Lists of Hazardous Wastes**
- Subtitle D – State or Regional Solid Waste Plans
  - **40CFR Part 257—Criteria for Classification of Solid Waste Disposal Facilities and Practices**
  - **40CFR Part 258—Criteria for Municipal Solid Waste Landfills**


All Materials
Garbage, refuse, or sludge
Solid, liquid, semi-solid, or contained gaseous DISCARDED material
Being used for intended purpose.
RCRA solid waste
N
Is your waste excluded from the lists of solid wastes?
Y
Not a RCRA solid waste
May be hazardous
Not hazardous under RCRA


RCRA Solid Waste
Is the solid waste listed or is it a mixture that contains a waste listed in Subpart D?
N
Does the waste exhibit any of the characteristics (Ignitability, Corrosivity, Reactivity, or Toxicity)?
Y
Y
N
Has the waste or mixture been excluded from the lists in Subpart D?
Y
N
Hazardous waste
Not a hazardous waste;
land disposal subject to Subtitle D

Waste Streams

- Liquid Residuals
  - Brine
  - Backwash water
  - Rinse water
  - Concentrate

- Solid Residuals
  - Spent resins
  - Spent media
  - Spent membranes
  - Sludges

Waste Identification

- Hazardous or non-hazardous?
  - Knowledge of the waste generation process
  - Toxicity Characteristic Leaching Procedure (TCLP) or Waste Extraction Test (WET)
  - Exemption for small quantity generators
- Mixed Waste?
  - Hazardous waste and > 0.05% uranium or thorium by weight (totaling <15 lbs.)

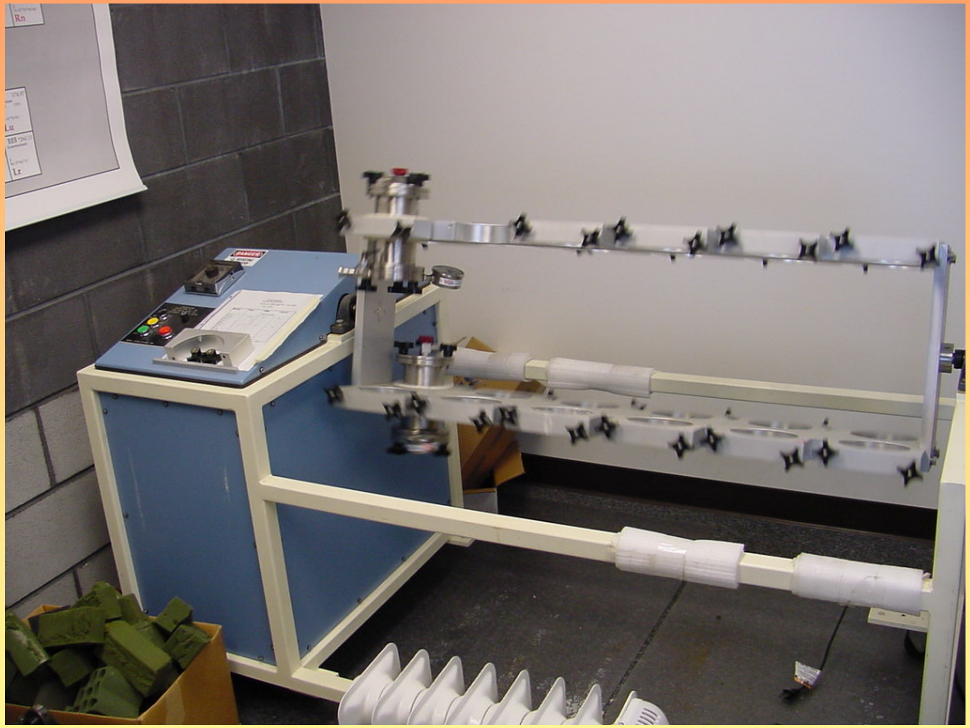
RCRA Regulatory Tests

- Paint Filter Liquids Test
- TCLP
  - Arsenic is one of the eight metals regulated under RCRA
  - Arsenic > 5.0 mg/L = Hazardous

Paint Filter Liquids Test

- Determines if "free" liquids are present
- Wastes containing free liquids banned from disposal in municipal and hazardous waste landfills

Toxicity Characteristic Leaching Procedure



- Predicts if hazardous components of a waste are likely to leach out
- Acetic acid extractant
- Regulatory levels established for
  - 8 metals
  - 32 organics
- Exceeding regulatory levels causes designation as hazardous waste

Waste Extraction Test (California Only)

- Predicts if hazardous components of a waste are likely to leach out
- Citric acid extractant
- Regulatory levels established for
  - 19 metals
  - 18organics
- More aggressive than TCLP for inorganics
- Exceeding regulatory levels causes designation as hazardous

Co-contamination

- Typical multiple contaminants where there is elevated Arsenic
- Some contaminants of concern:
  - Chromium (Cr6)
  - Uranium (U)
  - Nitrate (NO3)
  - Vanadium (V)

Waste Type: Mixed Waste

- Contains both hazardous waste and source. . . or byproduct material subject to the Atomic Energy Act
- Also regulated by RCRA

>0.05% U/Th by weight (totaling <15 lbs.) + Hazardous Waste = Mixed waste

Subject to license from NRC or Agreement State

Summary

- Is it a waste?
- Is it a Hazardous Waste?
  – Yes If listed or demonstrates hazardous characteristics
- How can you dispose of the waste?
  – Non-hazardous
    - Many options
  – Hazardous
    - Options more limited and expensive

Mitigation Checklist

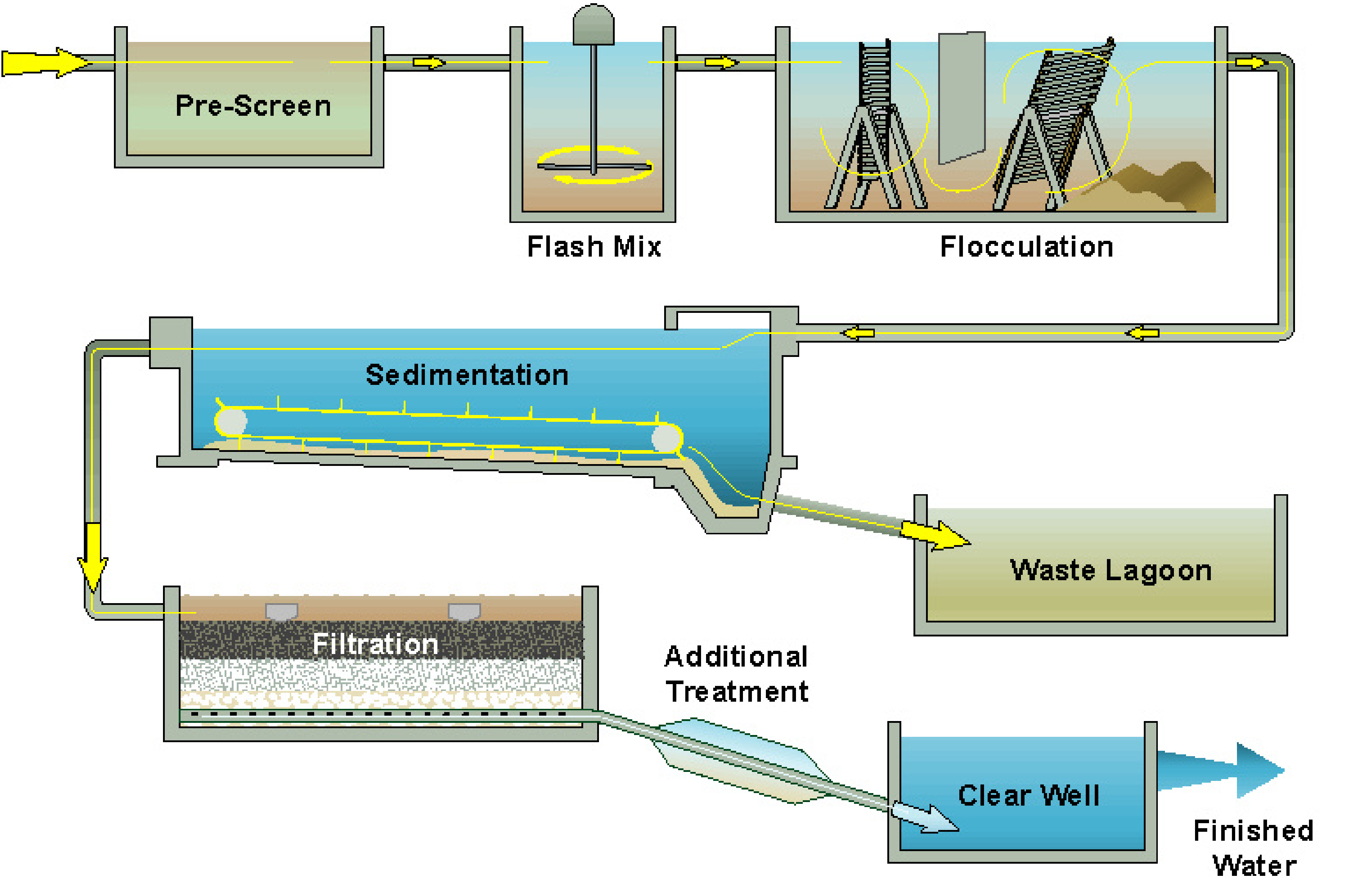
1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. **Select a mitigation strategy**
   a) Non-treatment options
      - Arsenic chemistry
      - Waste considerations
   b) Existing treatment
   c) New treatment technology
   d) POU
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan
11. Implement the strategy
12. Monitor at entry point

Decision Tree Overview

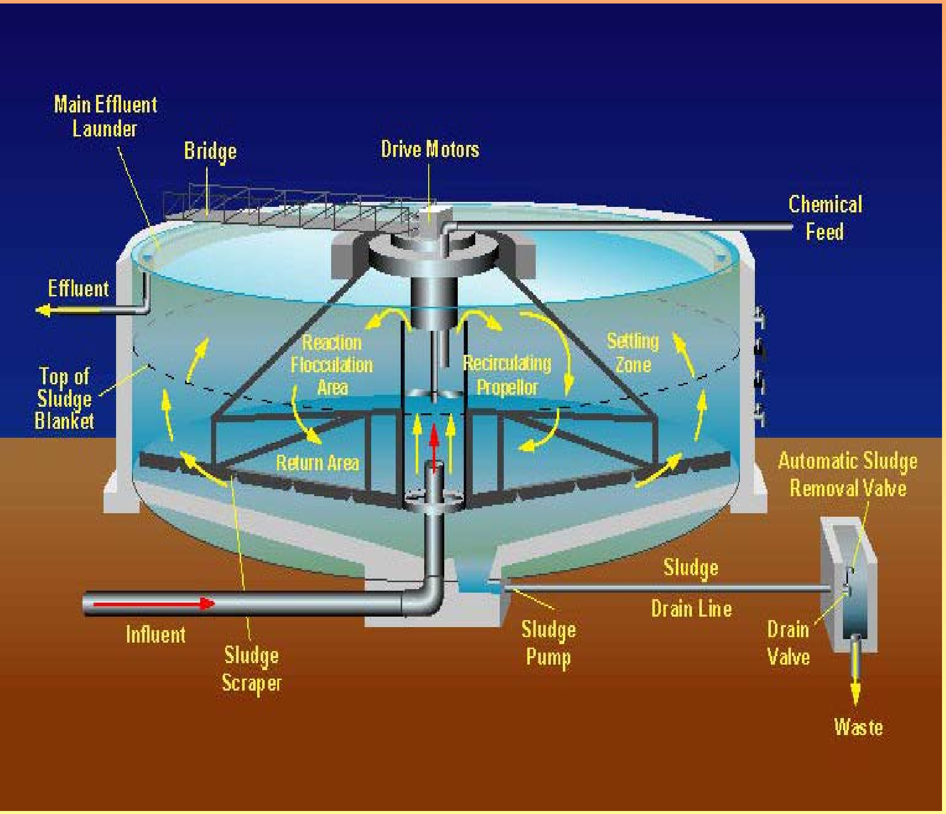
- Tree 1: Non-Treatment Alternatives
- Tree 2: Treatment Selection (Existing Treatment)
  - Tree 2a Enhanced Coagulation/Filtration
  - Tree 2b Enhanced Lime Softening
  - Tree 2c Iron & Manganese Filtration
- Tree 3: Selecting New Treatment
  - Tree 3a Ion Exchange Process
  - Tree 3b Sorption Processes
  - Tree 3c Filtration & Membrane Processes

Page 43, Figure 3-1. Decision Tree Overview

Conventional Treatment

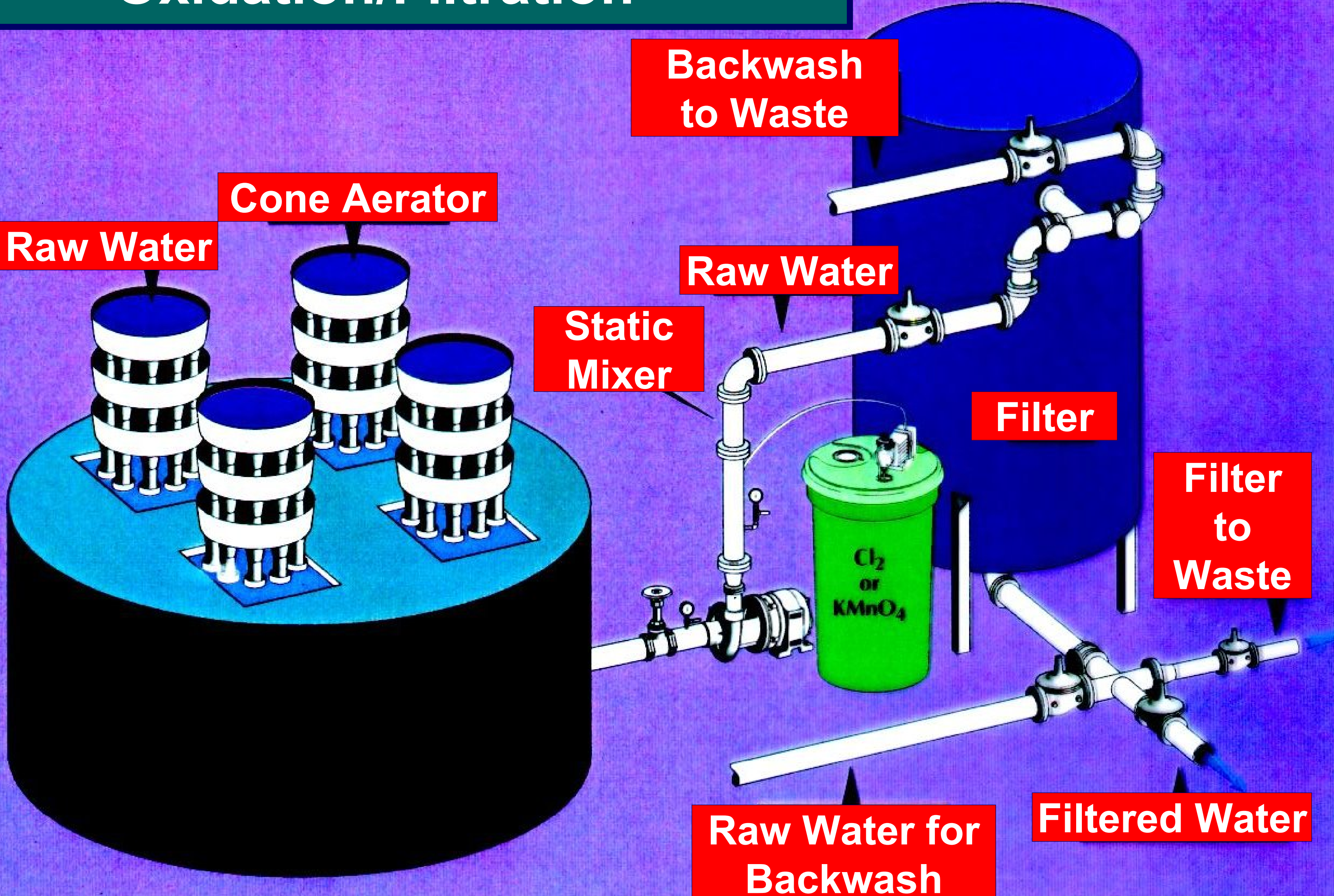


Enhanced Lime Softening



- **Arsenic V removal**
  - **pH >10.5**
  - **Magnesium hydroxide**
  - **May require**
    - **Mg addition**
    - **Ferric coagulant**

Iron and Manganese Removal Oxidation/Filtration



Coagulation/Softening/Iron Removal

- Pros
  - Uses existing technology
  - Removes other contaminants
- Cons
  - Costly

Iron removal may be attractive for systems With iron concentrations > 0.3. mg/L

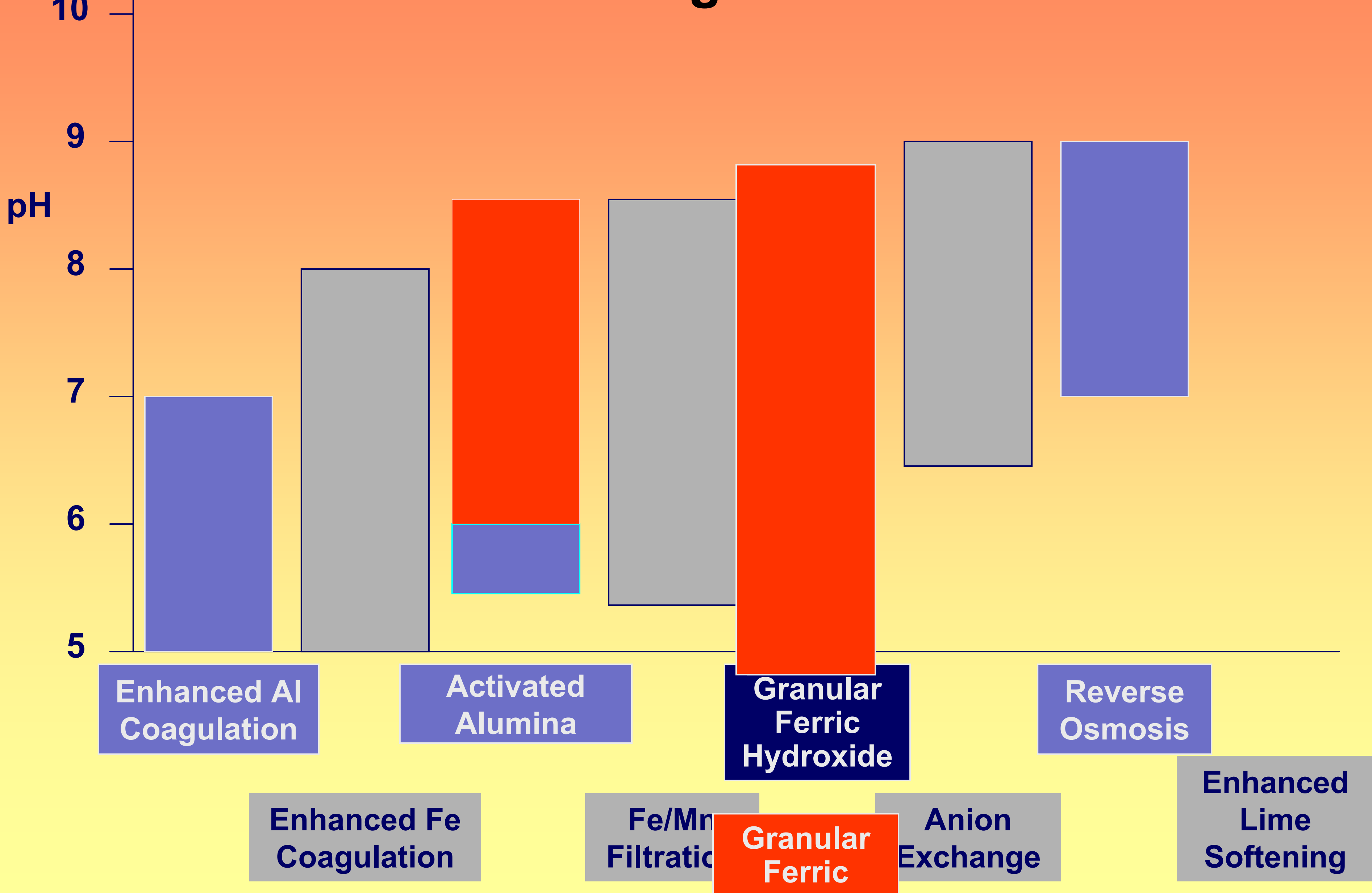
Residuals Produced

- Liquids
  - Backwash water
  - Supernatant
- Solids
  - Sludge
  - Media

3 Categories of Technologies

1. Sorption Processes
   - Ion Exchange (IX)
   - Activated Alumina (AA)
   - Iron Based Sorbents
2. Membrane Processes
   - Reverse Osmosis
3. Precipitation/Filtration Processes
   - Enhanced Coagulation / Filtration
   - Enhanced Lime Softening
   - Iron/Mn Oxidation/Filtration
   - Coagulation Assisted Membrane Filtration

Optimal pH Ranges for Arsenic Treatment Technologies

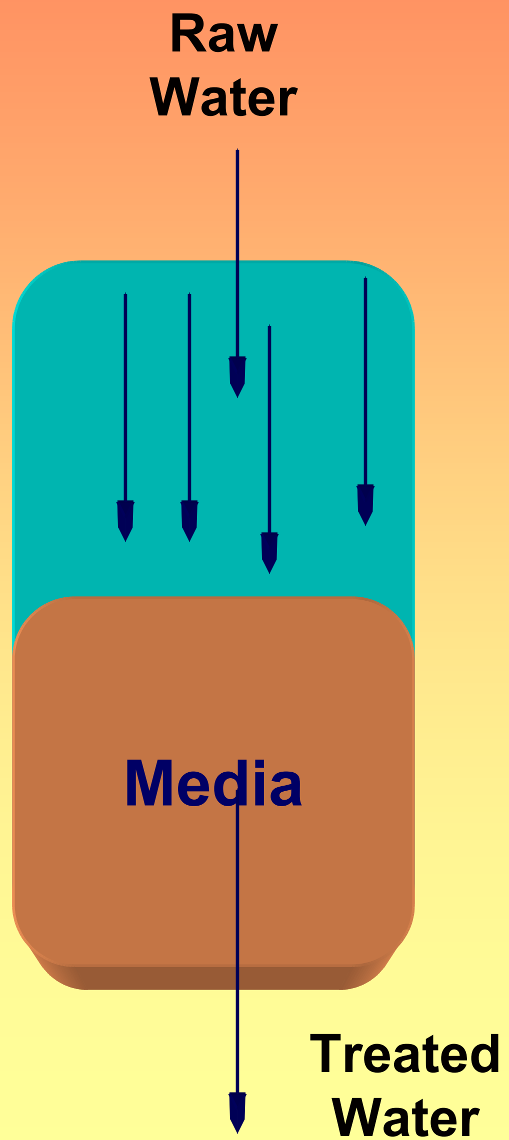


- **Throw-away adsorptive technologies are likely to be the treatment of choice for many small systems**
  - **Simple**
  - **Affordable**
  - **To some extent; flexible**

Ion Exchange

IX

Empty Bed Contact Time

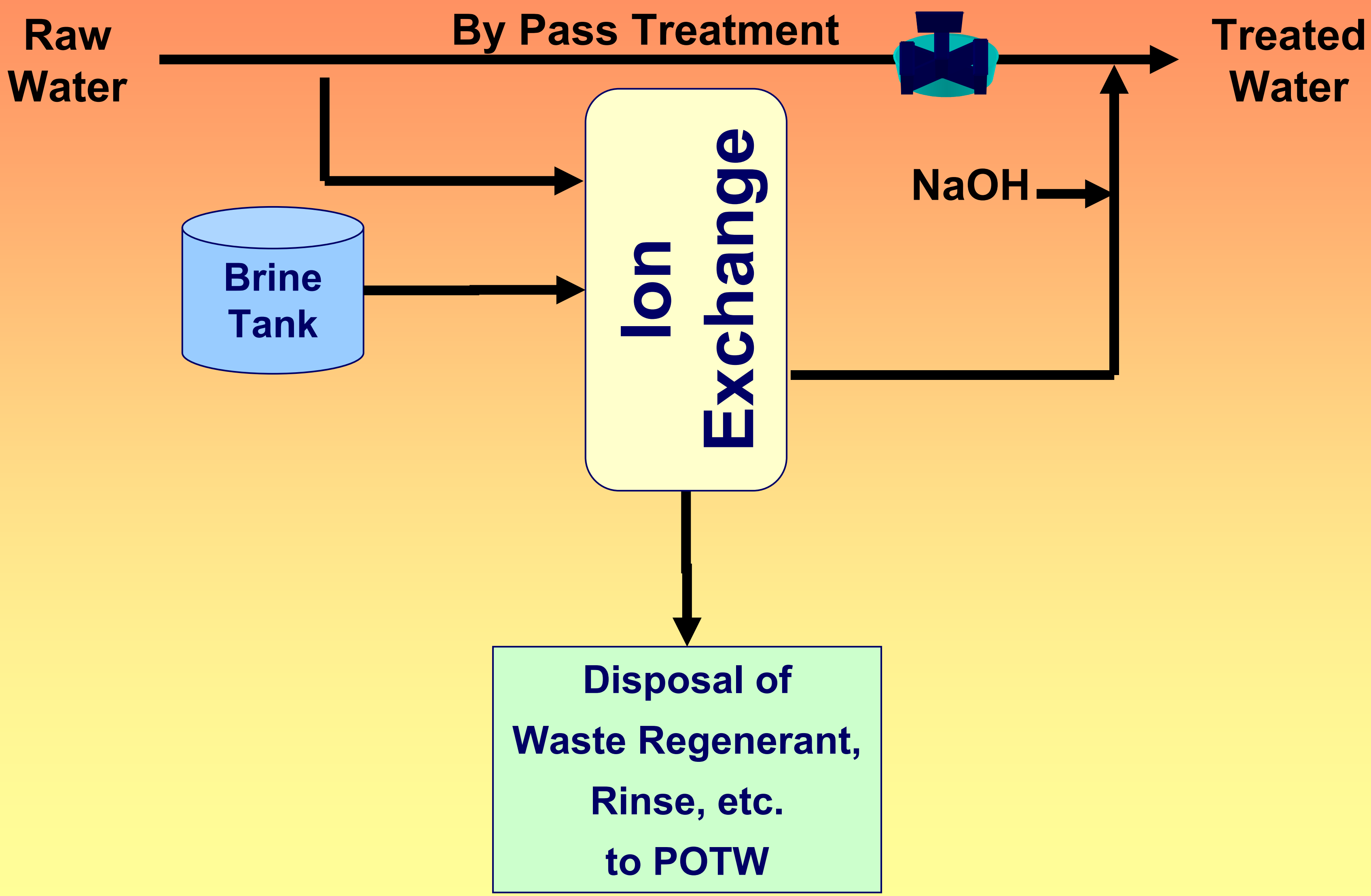


10 gallons of media
Flow rate of 2 gpm

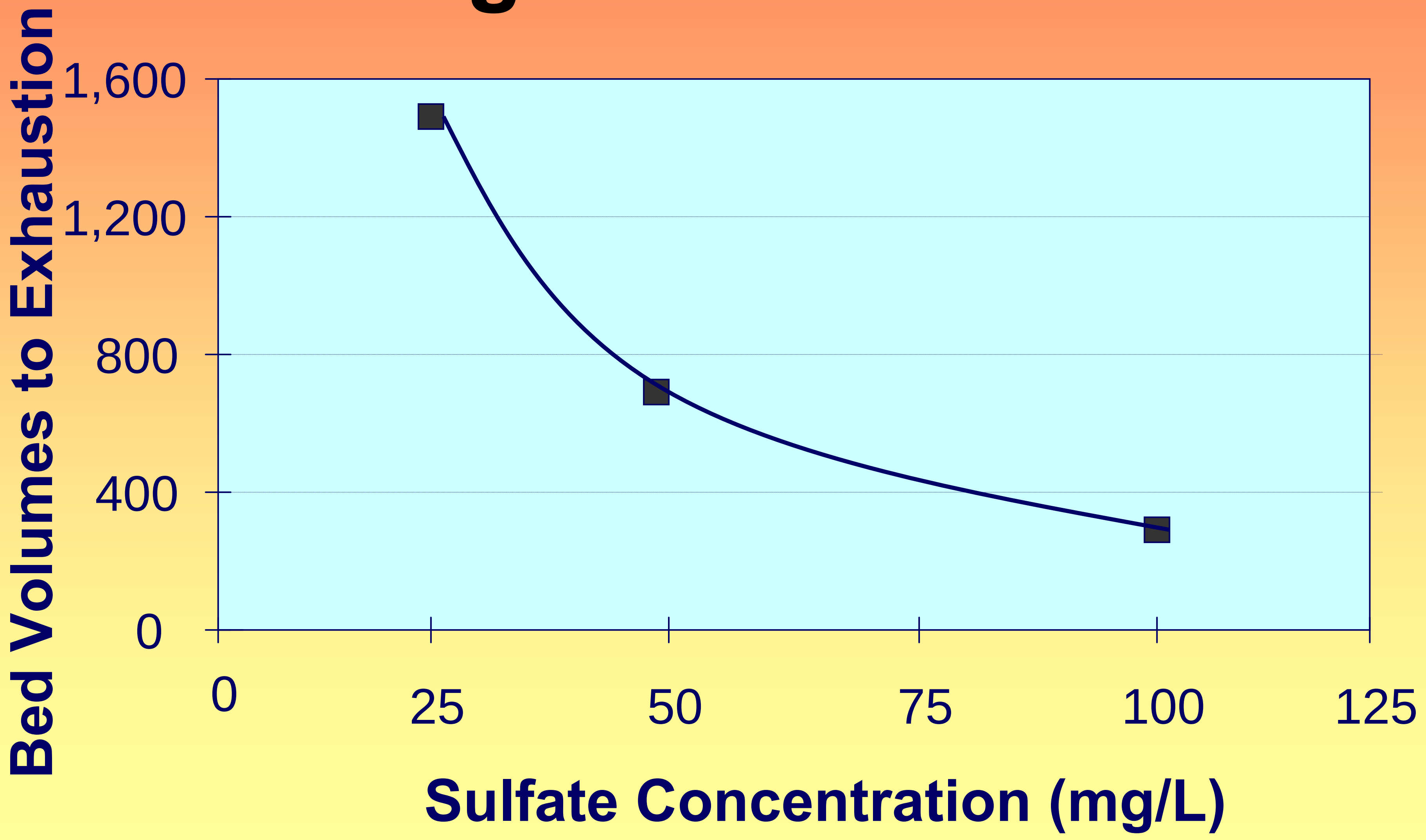
$$\text{EBCT} = \frac{10 \text{ gal}}{2 \text{ gpm}}$$

EBCT = 5 min.

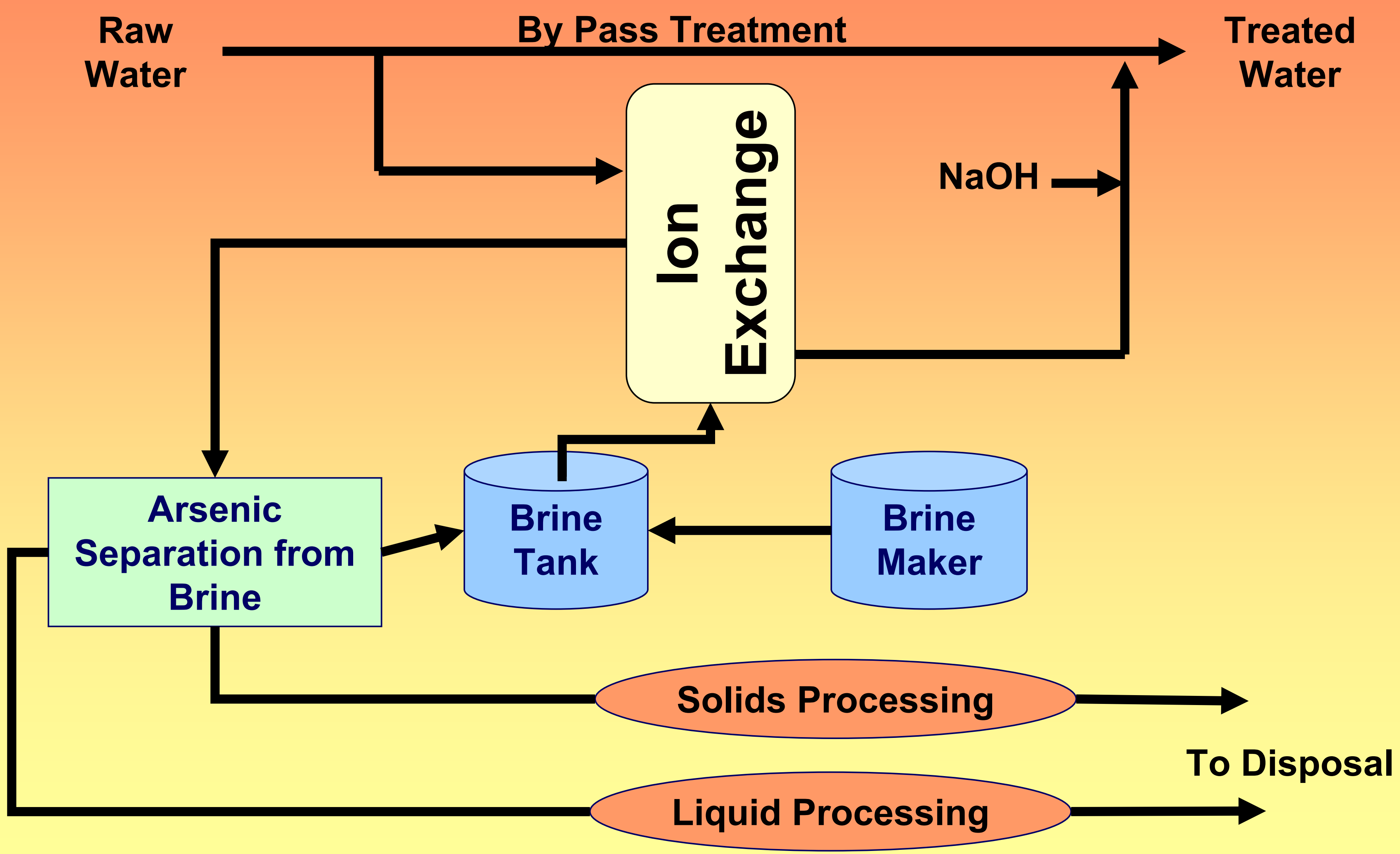
Ion Exchange Process



Effect of Sulfate on Ion Exchange Performance



Ion Exchange Process

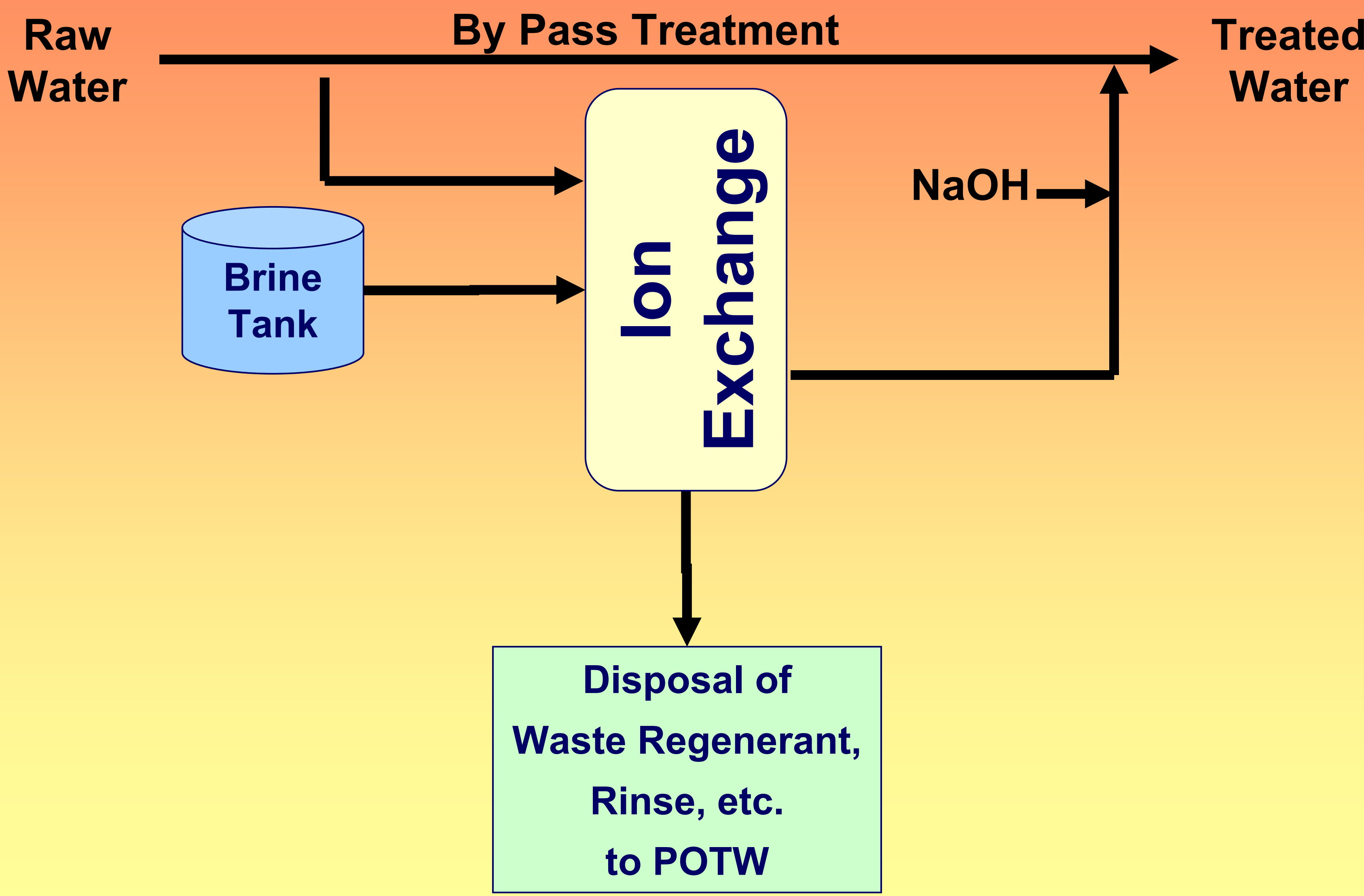


Decision Tree Overview

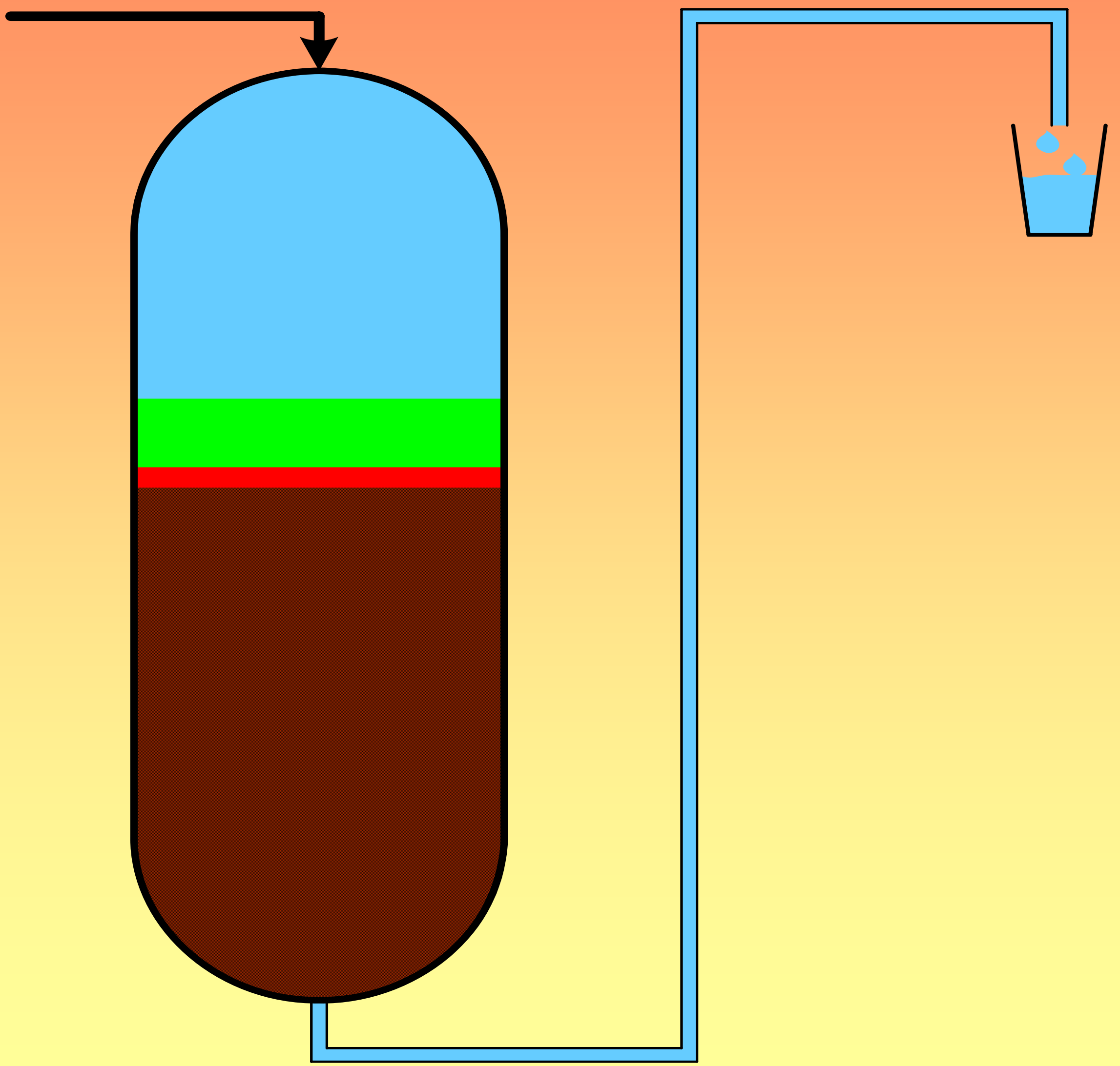
- Tree 1: Non-Treatment Alternatives
- Tree 2: Treatment Selection (Existing Treatment)
  - Tree 2a Enhanced Coagulation/Filtration
  - Tree 2b Enhanced Lime Softening
  - Tree 2c Iron & Manganese Filtration
- Tree 3: Selecting New Treatment
  - Tree 3a Ion Exchange Process
  - Tree 3b Sorption Processes
  - Tree 3c Filtration & Membrane Processes

Page 43, Figure 3-1. Decision Tree Overview

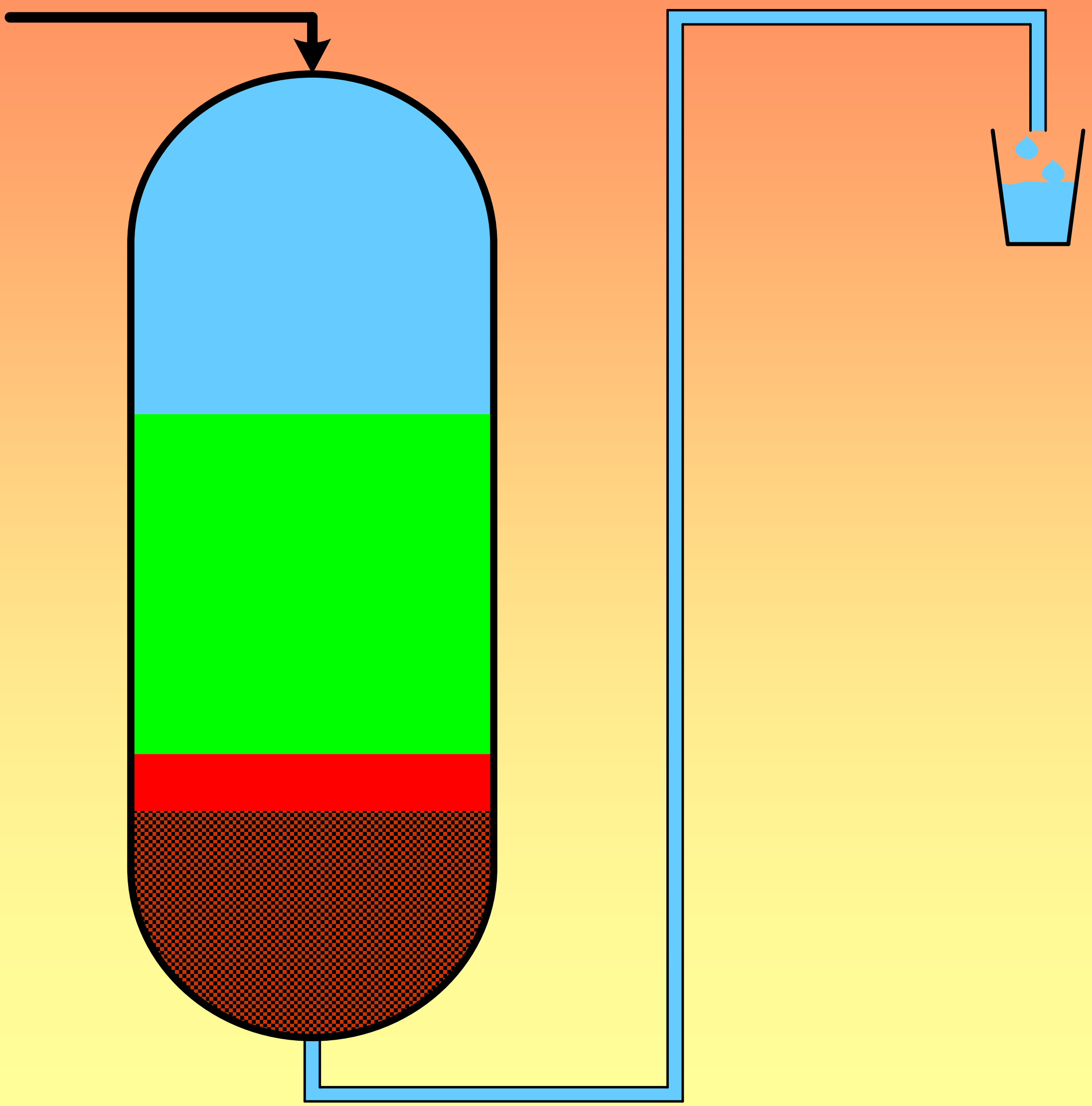
Chromatographic Peaking



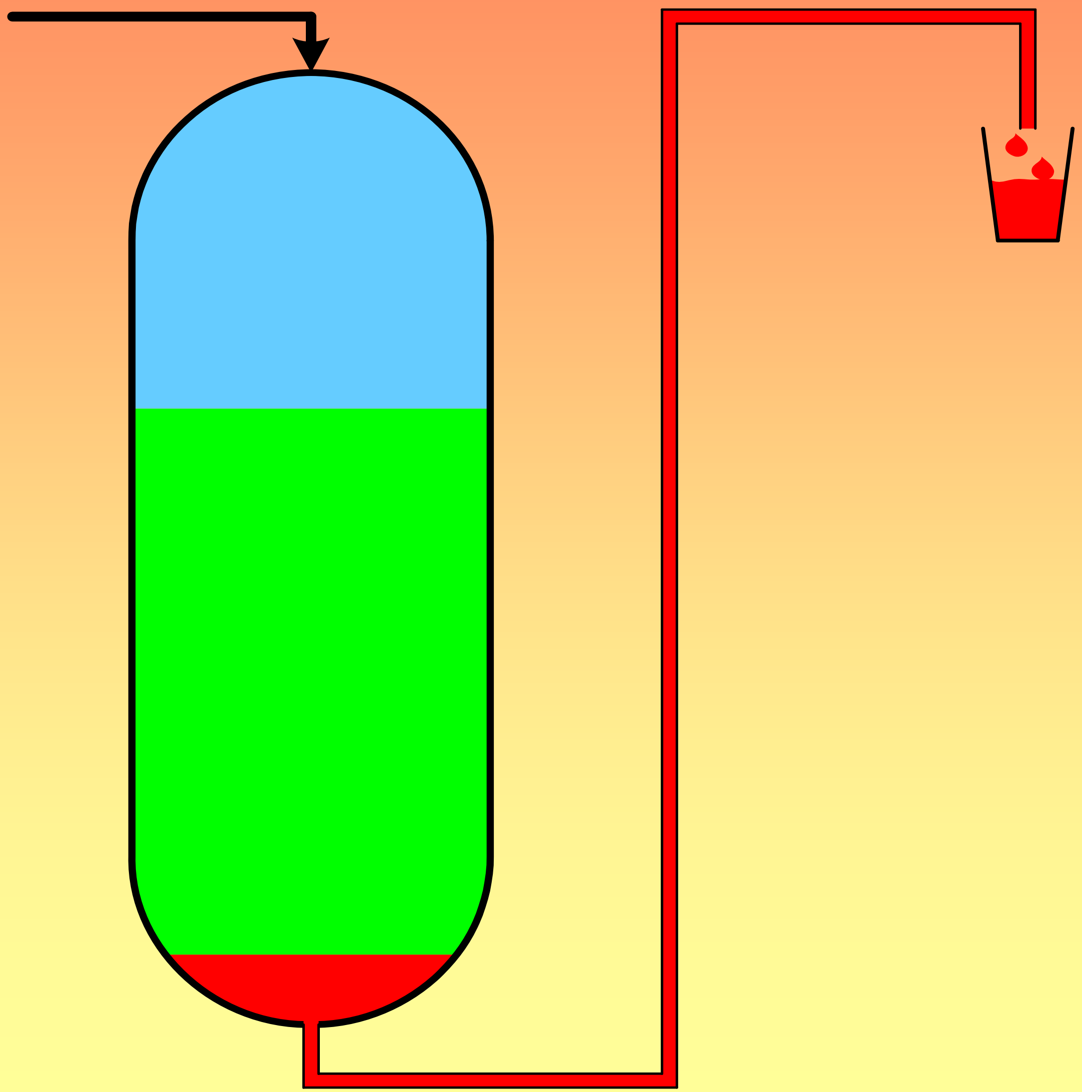
Chromatographic Peaking



Chromatographic Peaking



Chromatographic Peaking



Ion Exchange

Ion Exchange

Ion Exchange

- Pros
  - Operates on demand
  - Short contact time (flow insensitive)
    - (EBCT 1.5 - 3 min.)
  - Insensitive to pH
  - Capable of removing other contaminants
  - Resin can be regenerated
  - Appropriate for small systems
  - 98+% water recovery

Ion Exchange

- Cons
  - Excess oxidant may degrade resin
    - >0.1 mg/L free chlorine
  - Pre-filtration may be required
  - Sulfate can be a problem
  - Finished water pH adjustment may be required
    - removes bicarbonate alky, particularly at beginning of run
    - 2-5 columns in parallel may be appropriate
  - Chromatographic peaking
  - Large volumes of brine for disposal
    - May be a hazardous waste

Residuals

- Liquids
  - Backwash and rinse water
  - Brine
- Solids
  - Resin

Activated Alumina

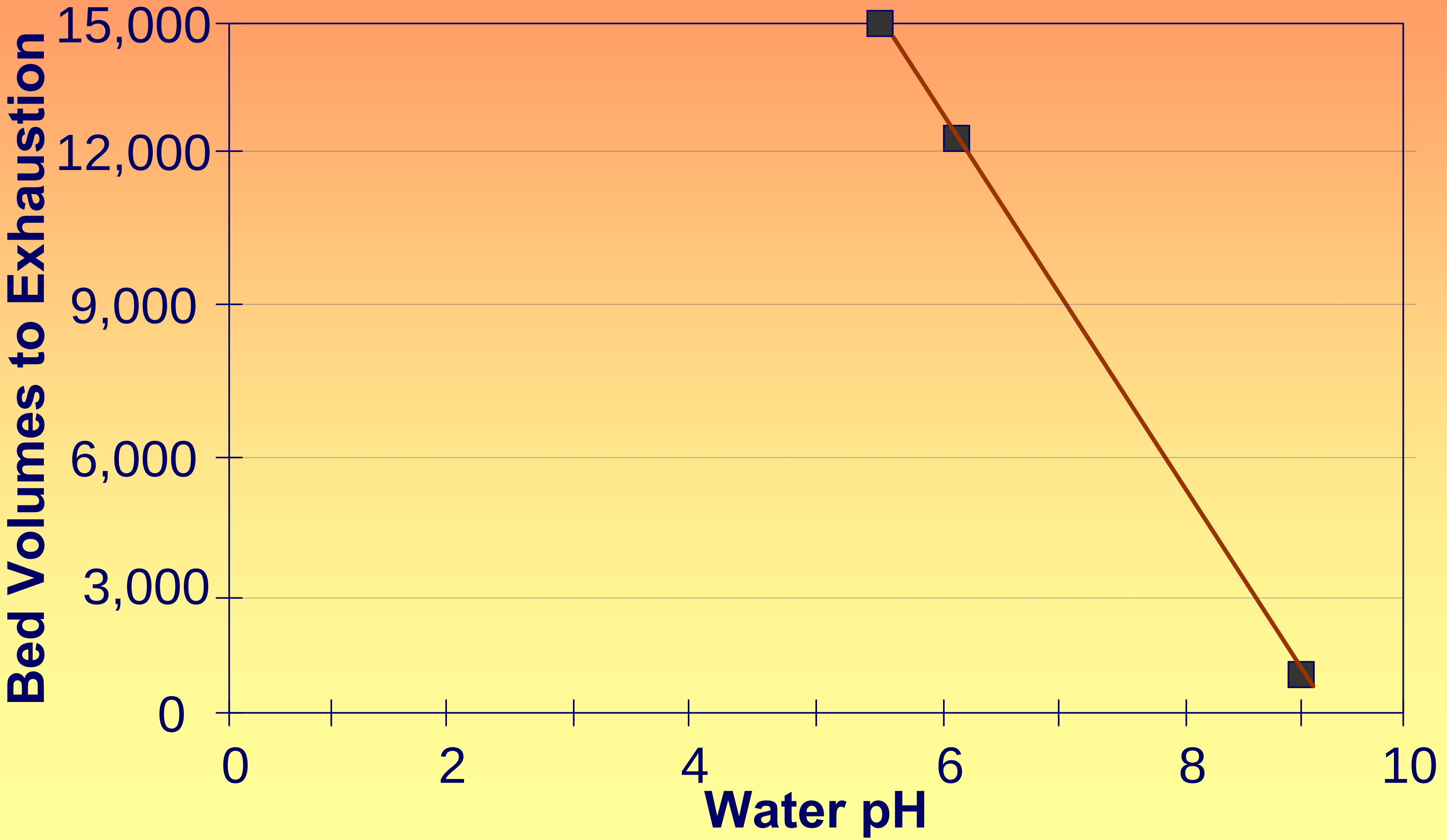
AA

Activated Alumina

- Porous granular media (aluminum trioxide) with ion exchange properties
- Competing ions

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

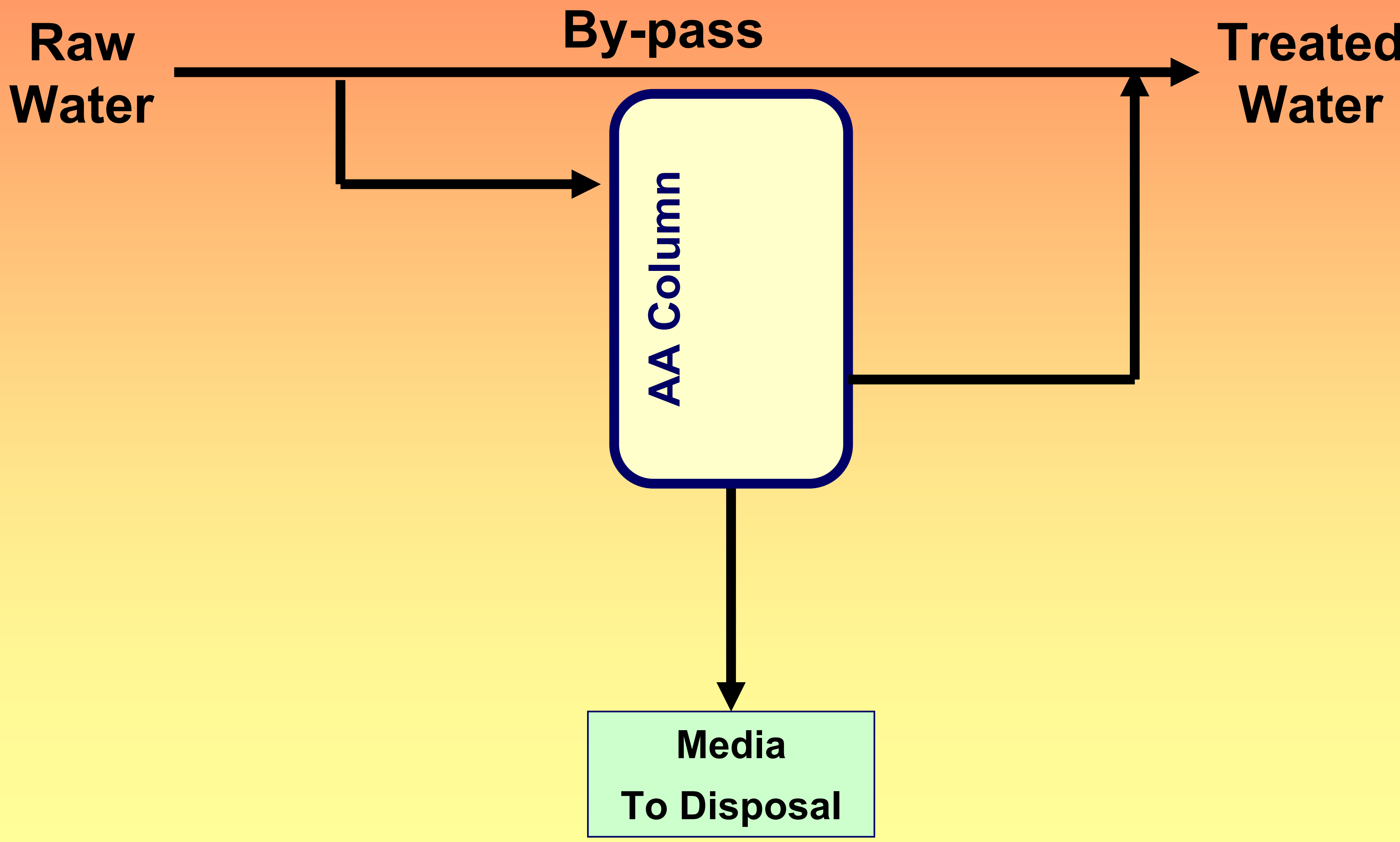
Effect of pH on Activated Alumina Performance



Water Quality Interferences with Activated Alumina Adsorption

Parameter	Problem Level
Chloride	250 mg/L
Fluoride	2 mg/L
Silica	30 mg/L
Iron	0.5 mg/L
Manganese	0.05 mg/L
Sulfate	720 mg/L
Dissolved Organic Carbon	4 mg/L
Total Dissolved Solids	1,000 mg/L

Activated Alumina Process (Throw-Away)



Activated Alumina

- Pros
  - Operates on demand
  - Relatively insensitive to TDS and sulfate
  - Highly selective for arsenic and fluoride
  - Can be regenerated
  - Disposable media option
  - 99+% recovery
  - Affordable

Activated Alumina

- Cons
  - Regeneration
    - Both acid and base required
      - May not be practical for small systems
    - Media tend to dissolve when regenerated
  - pH sensitive
      - Pre- and post-pH adjustment desirable
  - Slow adsorption kinetics
    - 3-10 min. EBCT

Residuals

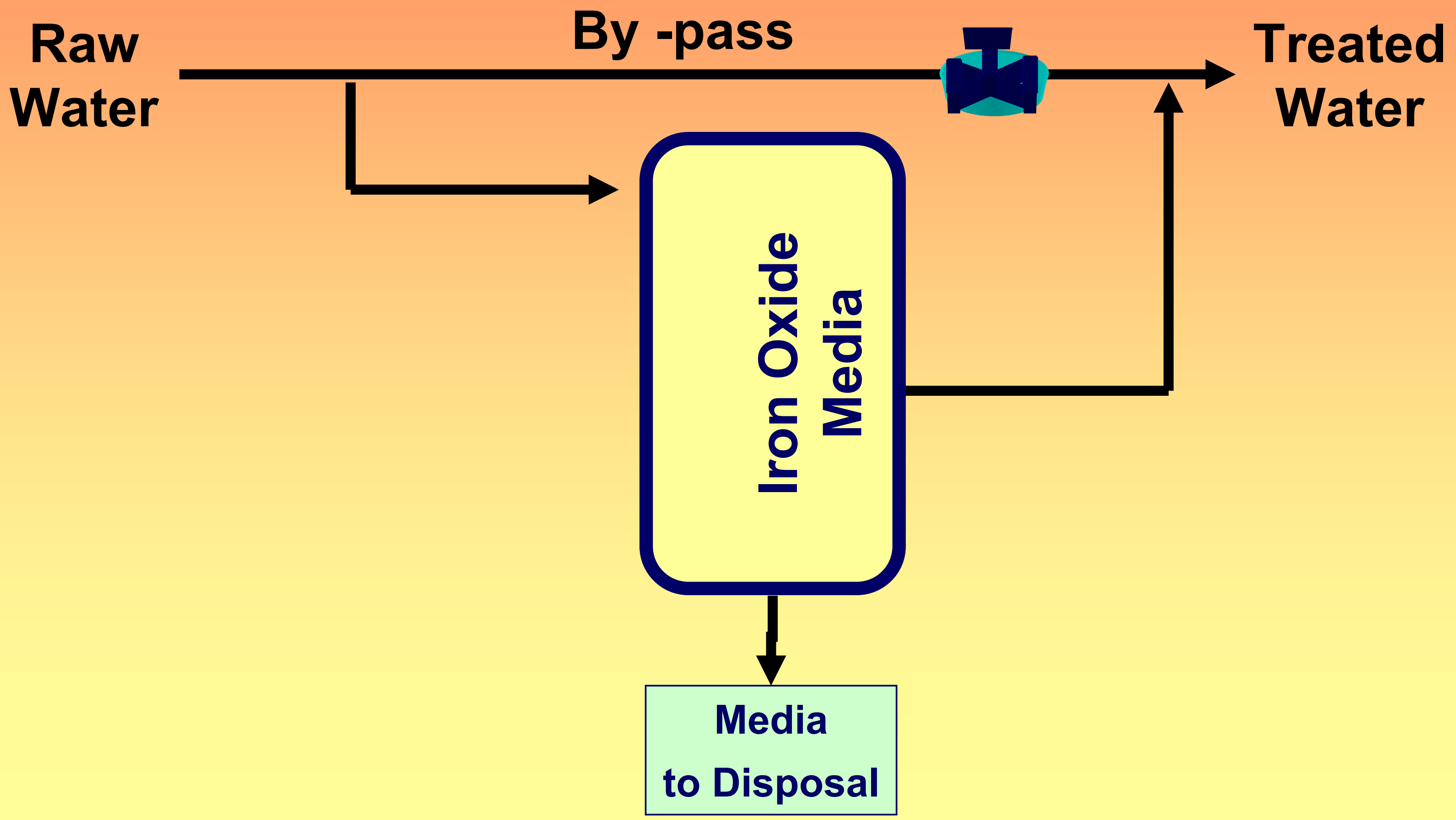
- Liquids
  - Backwash and rinse water
  - Spent regenerant
- Solids
  - Media

Throw-Away Activated Alumina

Full Scale Operation at a Small Community PWS

Iron-Based Sorbents

Iron-Based Sorbents



Iron-Based Sorbents
Rimrock, AZ

System Design/Operation

- Skid mounted
  - 8’ long X 4.5’ wide X 8.5’ tall
- Series operation
- 22 ft^3 of granular ferric oxide media
  - 32 gpm
  - 5.1 minutes EBCT
- Recycle of backwash water
- 12 hours/day operation
  - Since May, 2004
  - ~7,000,000 gallons of treated water

System Design/Operation

- Backwash once/month
  - 1,500 gallons/backwash
  - 0.2% of production water used for backwash
- 40,000 bed volumes in 9 months
  - Just now nearing MCL in finished water from vessel #1
- Media \$250 - \$320/ft^3
  - (\$5,500 - \$7,040/vessel)

Iron Based Sorbents

- Pros
  - Strong affinity to arsenic at natural pH
  - More bed volumes
  - 99+% recovery
  - Throw-away
  - Waste media passes TCLP and WET
  - May fail Total Threshold Limit Concentration in CA
- Cons
  - Phosphate interference
  - Silica interference

Residuals

- **Liquids**
  - Backwash water (potentially)
- **Solids**
  - Media

Disposable Media

- Conventional AA
- Proprietary AA
- Granular Ferric Hydroxide
- Proprietary Iron Oxides

Desirable Aspects:

- High As removal at natural pH
- Disposable; no regeneration required
- No hazardous wastes produced
- NSF 61 certified

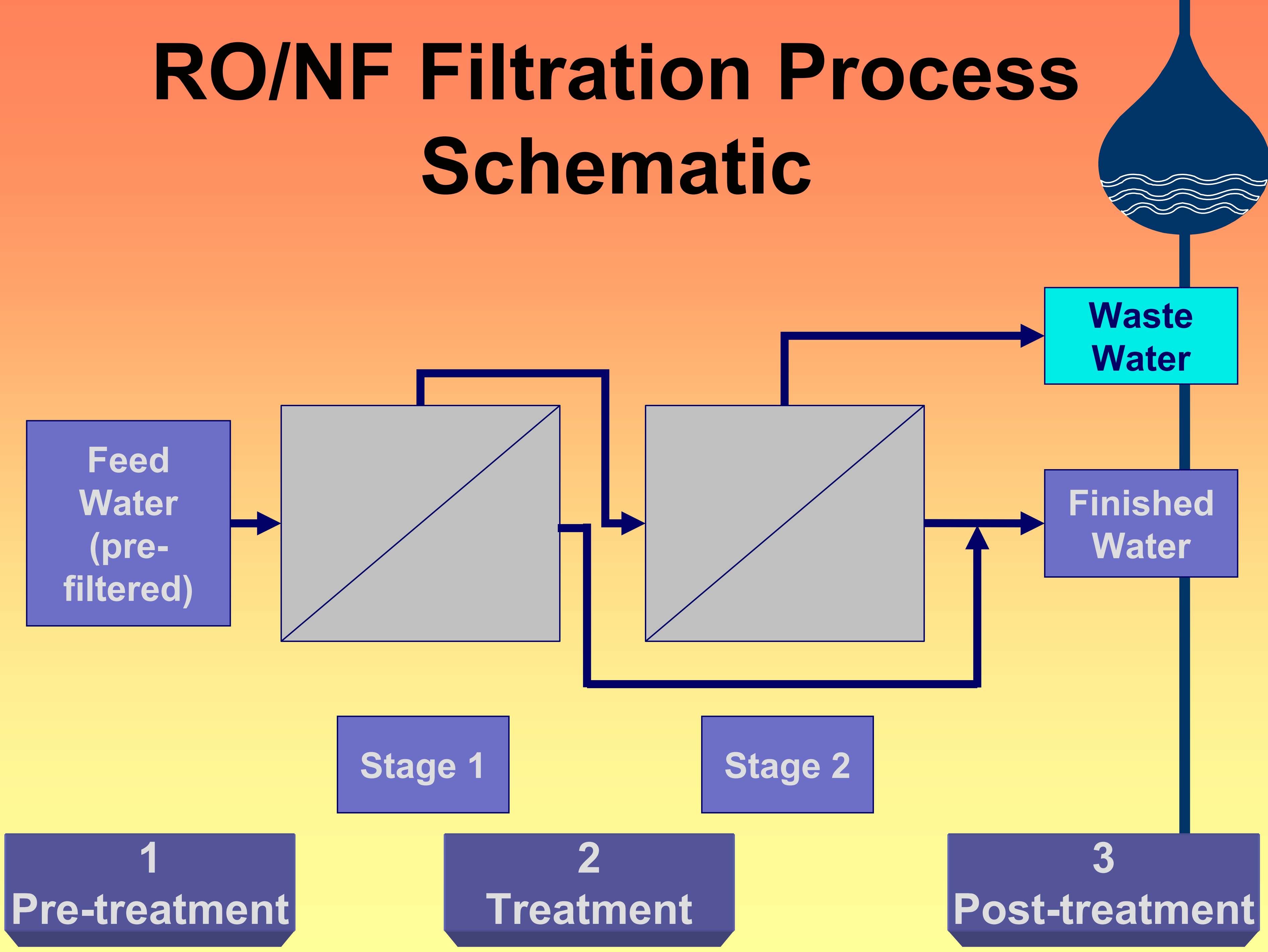
Membrane Processes

Reverse Osmosis

Nanofiltration

Coagulation Assisted Microfiltration

RO/NF Filtration Process Schematic



RO at a Small Community System

Reverse Osmosis/Nanofiltration

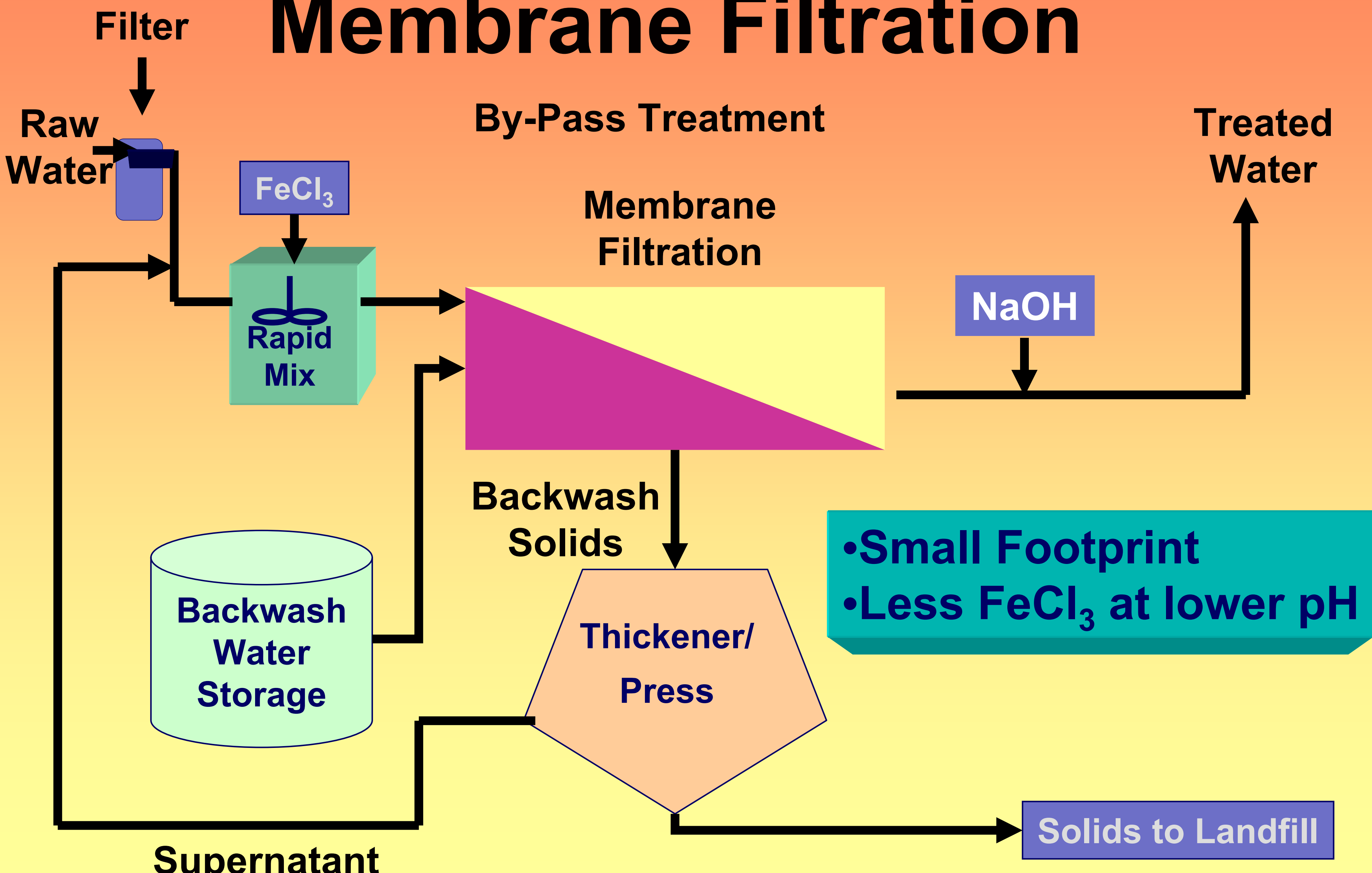
- Pros
  - Effective
  - Effective for removal of other contaminants
  - Applicable for POU or POE
- Cons
  - Pretreatment often required
    - Filtration
    - Cl_2 removal
  - Energy requirements
  - Water loss
  - Post treatment

Residuals

- **Liquids**
  - High TDS waste water
- **Solids**
  - Membranes

Coagulation Assisted Membrane Filtration

Coagulation Assisted Membrane Filtration



- Small Footprint
- Less $FeCl_3$ at lower pH

Micro Filtration Unit

Coagulation Assisted Membrane Filtration

- Pros
  - Minimal residuals
  - Very little water loss (< 0.1 %)
  - Relatively easy process control
  - Low chemical requirements
  - Small footprint
- Cons
  - High equipment costs
  - Coagulant dose is pH sensitive
  - Finished water pH adjustment may be necessary

Residuals

- Liquids
  - Backwash water
    - Can recycle
- Solids
  - Sludge
  - Membranes

Media Filtration

- With naturally occurring iron
- With coagulant addition

Pros, Cons, etc.
Very similar to oxidation/filtration and coagulation assisted membrane filtration.

Pages iv and 53

Table 3-3. Arsenic Treatment Technologies Summary Comparison. (1 of 2)

Factors	Sorption Processes			Membrane Processes
	Ion Exchange	Activated Alumina [A]	Iron Based Sorbents	Reverse Osmosis
	IX	AA	IBS	RO
USEPA BAT [B]	Yes	Yes	No [C]	Yes
USEPA SSCT [B]	Yes	Yes	No [C]	Yes
System Size [B,D]	25-10,000	25-10,000	25-10,000	501-10,000
SSCT for POU [B]	No	Yes	No [C]	Yes
POU System Size [B,D]	-	25-10,000	25-10,000	25 -10,000
Removal Efficiency	95% [E]	95% [E]	up to 98% [E]	> 95% [E]
Total Water Loss	1-2%	1-2%	1- 2%	15-75%
Pre-Oxidation Required [F]	Yes	Yes	Yes [G]	Likely [H]
Optimal Water Quality Conditions	pH 6.5 - 9 [E] < 5 mg/L NO_3^{-1} [I] < 50 mg/L SO_4^{2-} [J] < 500 mg/L TDS [K] < 0.3 NTU Turbidity	pH 5.5 - 6 [I] pH 6 - 8.3 [L] < 250 mg/L Cl^- [I] < 2 mg/L F^- [I] < 360 mg/L SO_4^{2-} [K] < 30 mg/L Silica [M] < 0.5 mg/L Fe^{+3} [I] < 0.05 mg/L Mn^{+2} [I] < 1,000 mg/L TDS [K] < 4 mg/L TOC [K] < 0.3 NTU Turbidity	pH 6 - 8.5 < 1 mg/L PO_4^{-3} [N] < 0.3 NTU Turbidity	No Particulates
Operator Skill Required	High	Low [A]	Low	Medium
Waste Generated	Spent Resin, Spent Brine, Backwash Water	Spent Media, Backwash Water	Spent Media, Backwash Water	Reject Water
Other Considerations	Possible pre & post pH adjustment. Pre-filtration required. Potentially hazardous brine waste. Nitrate peaking. Carbonate peaking affects pH.	Possible pre & post pH adjustment. Pre-filtration may be required. Modified AA available.	Media may be very expensive. [O] Pre-filtration may be required.	High water loss (15-75% of feed water)
Centralized Cost	Medium	Medium	Medium	High
POU Cost	-	Medium	Medium	Medium

Pages v and 54

Table 3-3. Arsenic Treatment Technologies Summary Comparison. (2 of 2)

Factors	Precipitative Processes				
	Enhanced Lime Softening	Enhanced (Conventional) Coagulation Filtration	Coagulation-Assisted Micro-Filtration	Coagulation-Assisted Direct Filtration	Oxidation Filtration
	LS	CF	CMF	CADF	OxFilt
USEPA BAT [B]	Yes	Yes	No	Yes	Yes
USEPA SSCT [B]	No	No	Yes	Yes	Yes
System Size [B,D]	25-10,000	25-10,000	500-10,000	500-10,000	25-10,000
SSCT for POU [B]	No	No	No	No	No
POU System Size [B,D]	-	-	-	-	-
Removal Efficiency	90% [E]	95% (w/ $FeCl_3$) [E] < 90% (w/ Alum) [E]	90% [E]	90% [E]	50-90% [E]
Total Water Loss	0%	0%	5%	1-2%	1-2%
Pre-Oxidation Required [F]	Yes	Yes	Yes	Yes	Yes
Optimal Water Quality Conditions	pH 10.5 - 11 [I] > 5 mg/L Fe^{+3} [I]	pH 5.5 - 8.5 [P]	pH 5.5 - 8.5 [P]	pH 5.5 - 8.5 [P]	pH 5.5 - 8.5 >0.3 mg/L Fe Fe:As Ratio > 20:1
Operator Skill Required	High	High	High	High	Medium
Waste Generated	Backwash Water, Sludge (high volume)	Backwash Water, Sludge	Backwash Water, Sludge	Backwash Water, Sludge	Backwash Water, Sludge
Other Considerations	Treated water requires pH adjustment.	Possible pre & post pH adjustment.	Possible pre & post pH adjustment.	Possible pre & post pH adjustment.	None.
Centralized Cost	Low [Q]	Low [Q]	High	Medium	Medium
POU Cost	N/A	N/A	N/A	N/A	N/A

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
   a) Non-treatment options
   b) Existing treatment
   c) New treatment technology
   d) POU
      - Presentation
      - Section 8, page 117
7. Estimate capital and O & M costs
   Section 4, page 55
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
   a) Non-treatment options
   b) Existing treatment
   c) New treatment technology
   d) POU

      Presentation

      Section 8, page 117
7. Estimate capital and O & M costs

   Section 4, page 55

8. Evaluate design considerations

- Section 5 – Oxidation
- Section 6 – Sorption Processes
- Section 7 – Pressure Media Filtration
- State review and general design considerations

Authority for Plan Review

- States typically have authority that addresses:
  - Design standards
  - Construction permit
  - Engineer's certification and as-built plans
  - Operating permit
  - Professional engineer

Questions for Engineers

Plan Review Process

- Typically consists of:
  - Engineering report
    - Project description
    - Design criteria
    - Supporting calculations
  - Plans and specifications
  - Pilot testing may be required

Review Process

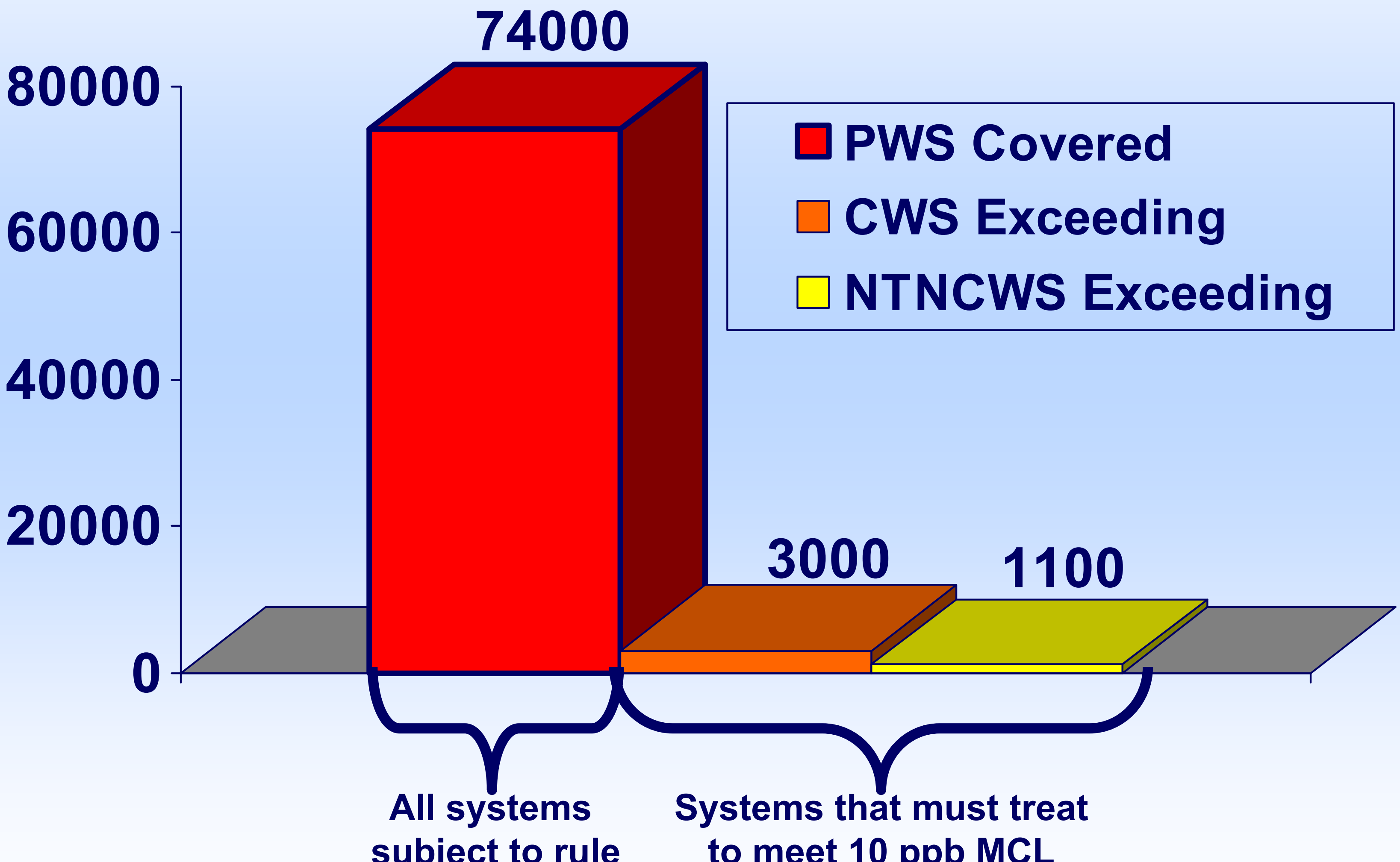
- The process is intended to make sure:
  - Minimum standards are met and
  - Public health is protected

Check with the State to make sure you know the minimum standards and requirements.

See the state-specific materials in your binder.

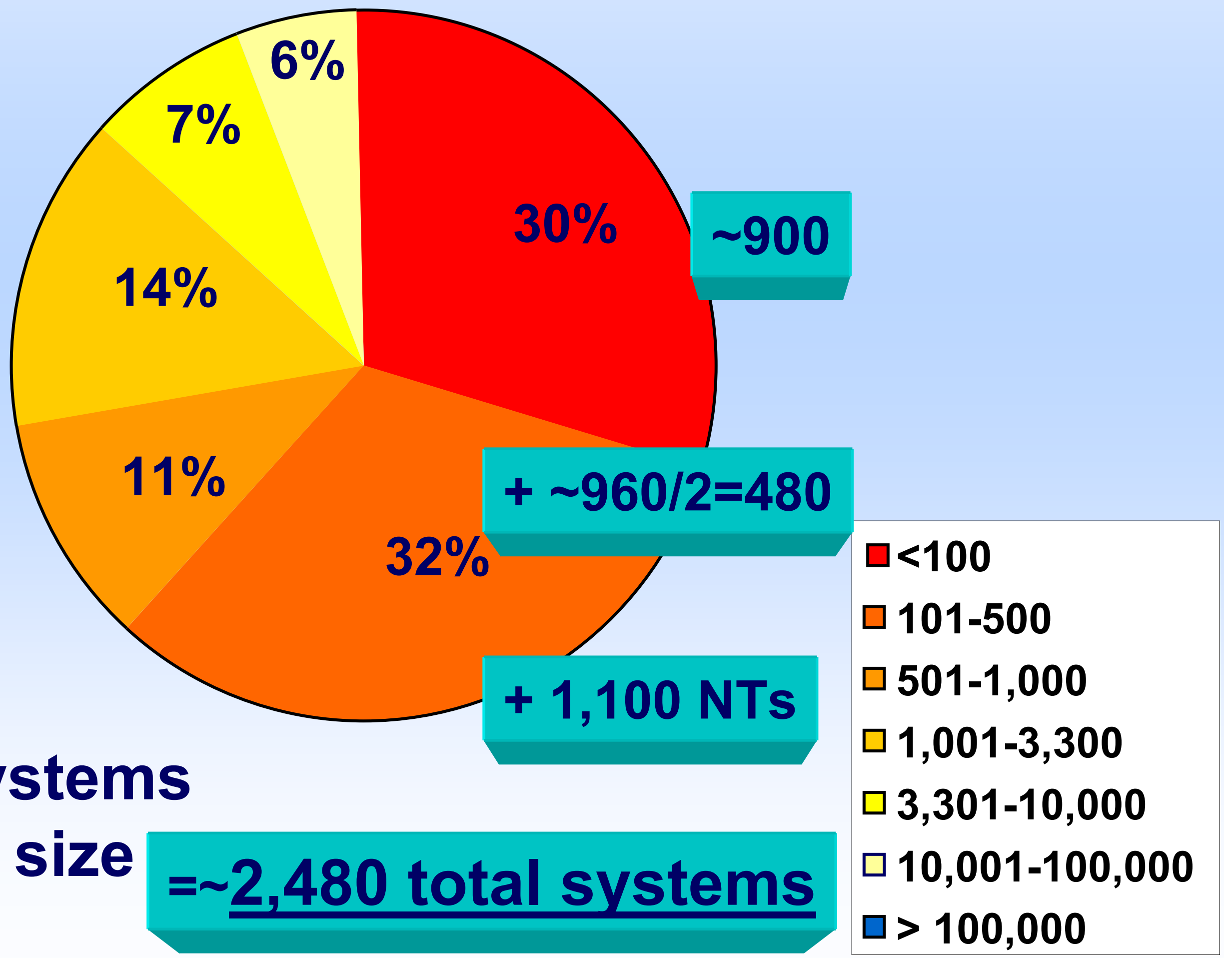
Design Issues

Number of Systems Affected by Arsenic Rule



4,100 total

Most Of The ~3000 CWSs Affected by the Arsenic Rule Are Very Small



Percentage of systems serving different size populations

General Design and Cost Considerations

- As capacity is increased
  - Total costs generally go up
  - Unit costs go down
- Small system issues
  - Systems with storage
    - Tendency to have “oversized” source water pumps
  - Hydropneumatic tanks
    - BIG portion of small systems

Example System
(Gravity Storage)

- **Small community system**
  - Twenty service connections
  - Single well (50 gpm pump)
  - 50,000 gallon gravity storage tank
  - Average day = 8,000 gallons
  - Max day = 20,000 gallons

$$\frac{20{,}000 \text{ gal.}}{(50 \text{ gpm})(60 \text{ min/hr})} = 6.7 \text{ hours/day}$$

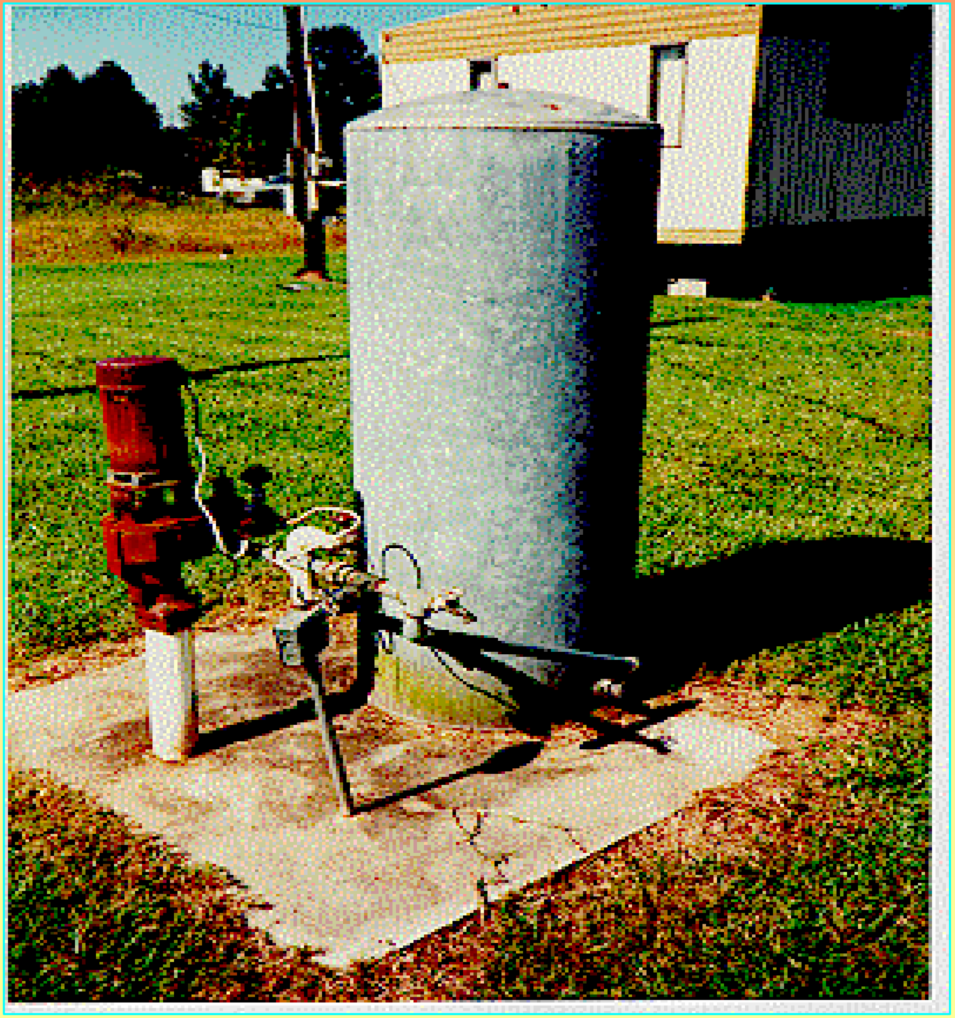
Alternatives

1) Design for existing well pump capacity
   - ❑ 50 gpm

2) Design for max day with safety factor
   - ❑ Figure 20 hours/day production

$$\frac{20{,}000 \text{ gallons}}{60 \text{ min/hr} \times 20 \text{ hr/day}} = 17.7 \text{ gpm}$$

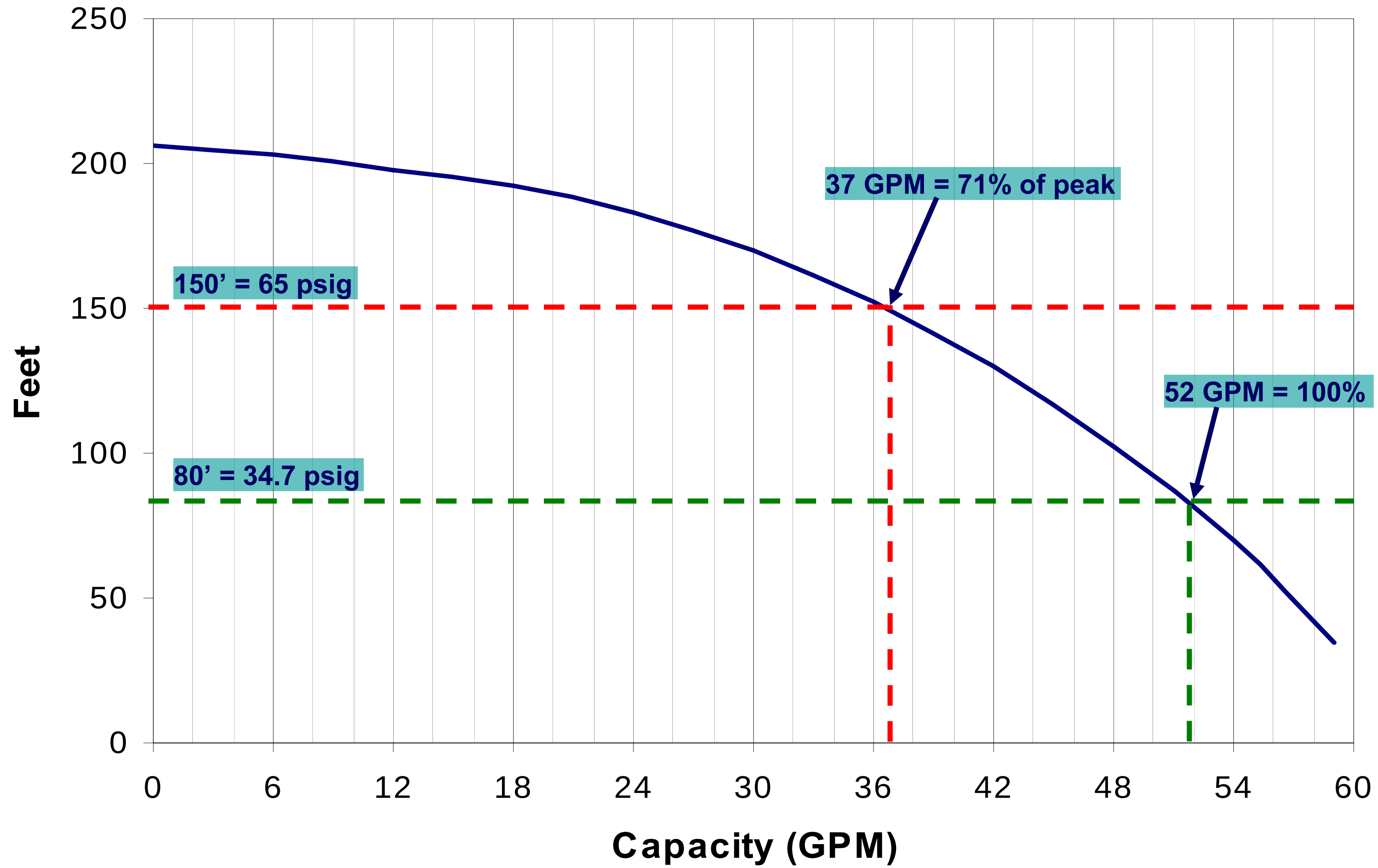
Design Considerations
(Hydropneumatic Storage)



- Configuration
  - Pressure tank systems
    - Treat peak demand
  - Install storage
    - Treat max day +

Example System
(Hydropneumatic Storage)

- Small community system
  - Twenty service connections
  - Single well
    - Pump rated at 44 gpm
  - Battery of captive air tanks
  - Peak instantaneous demand = 52 gpm
  - Average day = 8,000 gallons
  - Max day = 20,000 gallons



37 GPM = 71% of peak
150' = 65 psig
52 GPM = 100%
80' = 34.7 psig
Feet
250
200
150
100
50
0
0
6
12
18
24
30
36
42
48
54
60
Capacity (GPM)

Alternatives

1) Design for peak instantaneous flow
   - 52 gpm

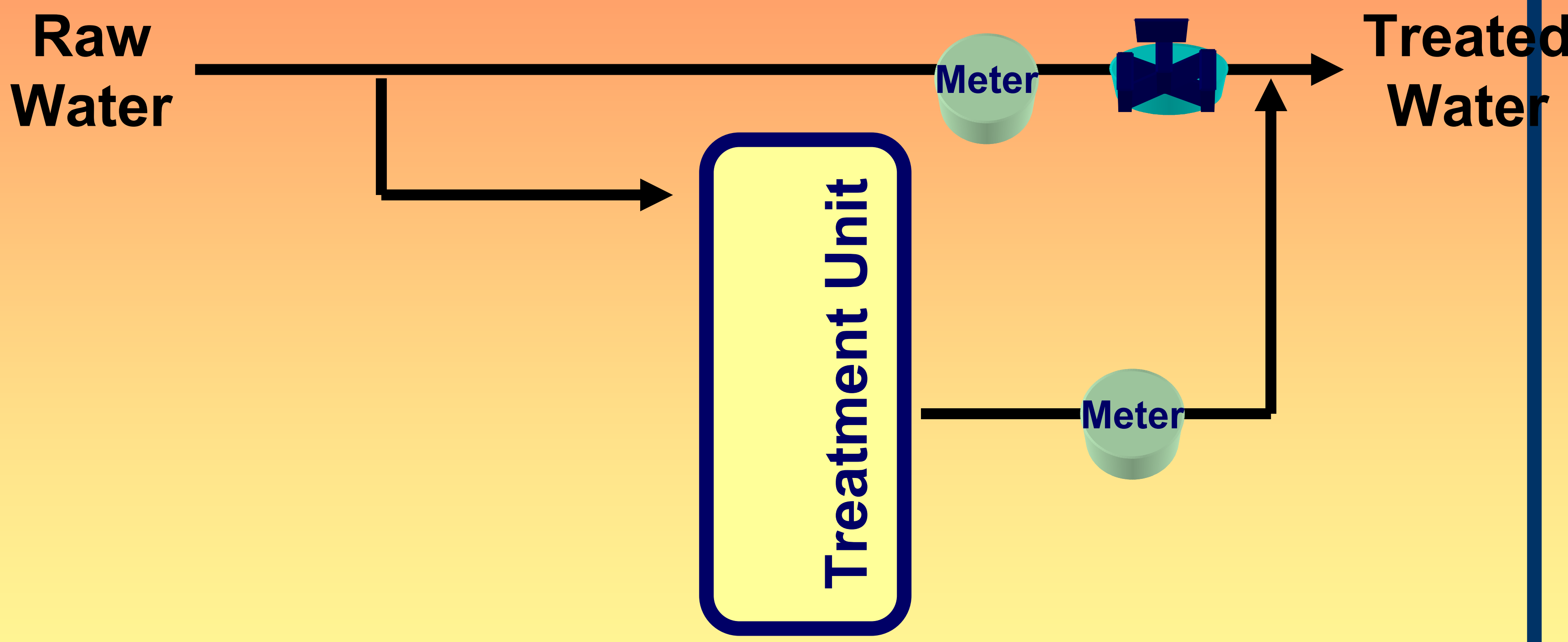
2) Add storage and design for max day with safety factor
   - Figure 20 hours/day production

$$\frac{20{,}000 \text{ gallons}}{60 \text{ min/hr} \times 20 \text{ hr/day}} = 17.7 \text{ gpm}$$

General Regulatory Design Considerations

- Configuration
  - Parallel
  - Series
  - Guard columns
- Split stream treatment
- Redundancy
- Pre-treatment
- Post-treatment
- Residuals
- Automation
- Loading rates

Split Stream Treatment



Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. **Pilot test**
10. **Develop construction cost estimates and plan**
11. **Implement the strategy**
12. **Monitor at entry point**

Testing Your Selection

- How do you protect yourself?
  1. Design and build
  2. Bench scale testing
  3. Pilot testing
  4. Make use of reputable vendors
     a. Low bidder approach
     b. Seek warranties/leases
     c. Ask appropriate questions

1. Design and Build

- Some risk associated with this approach
  - The media
    - May not work
    - May cost too much
    - May create a hazardous waste
- Flexibility in design may provide some protection
  - E.g., design for conservative EBCT

2. Bench Scale Testing

- Rapid Small Scale Column Testing
  - Uses laboratory columns
    - Small diameter media
    - Small diameter columns
    - Reduced EBCT
  - This process may allow scaling up to full-scale with full-sized media
  - Faster and less expensive than piloting

Rapid Small Scale Column Testing For Evaluating Arsenic Adsorbents, 2004,AWWARF

2. Bench Scale Testing

- Jar Testing
  - Where oxidation/coagulation/filtration appear promising
    - Add chlorine and mix to oxidize As III
    - Add varying doses of ferric chloride
    - Mix 20 seconds
    - Filter
  - Where oxidation/filtration appears promising
    - Add chlorine
    - Mix
    - Filter

3. Pilot Testing

- The pros
  - Answers questions
    - Will it work?
    - Net water production
    - Finished water quality
    - Waste production
      - Hazardous?
    - Impact of variables
      - pH adjustment
      - EBCT
    - Costs
  - Develop site-specific design criteria

3. Pilot Testing

- The cons
  - Costly
    - Equipment
    - Manpower
    - Technical expertise
  - Time
    - Assume you can get 30,000 bed volumes before loading the adsorptive media

$$\frac{(30{,}000\ \text{BVs})(5\ \text{min./BV})}{1440\ \text{min/day}} = 104\ \text{days}$$

Considerations in Piloting

- Key factors:
  - Ability to remove arsenic
    - Impact of competing ions
  - The capacity of the media
  - Pre-treatment requirements
    - Oxidation
    - pH
  - Residuals
  - Costs

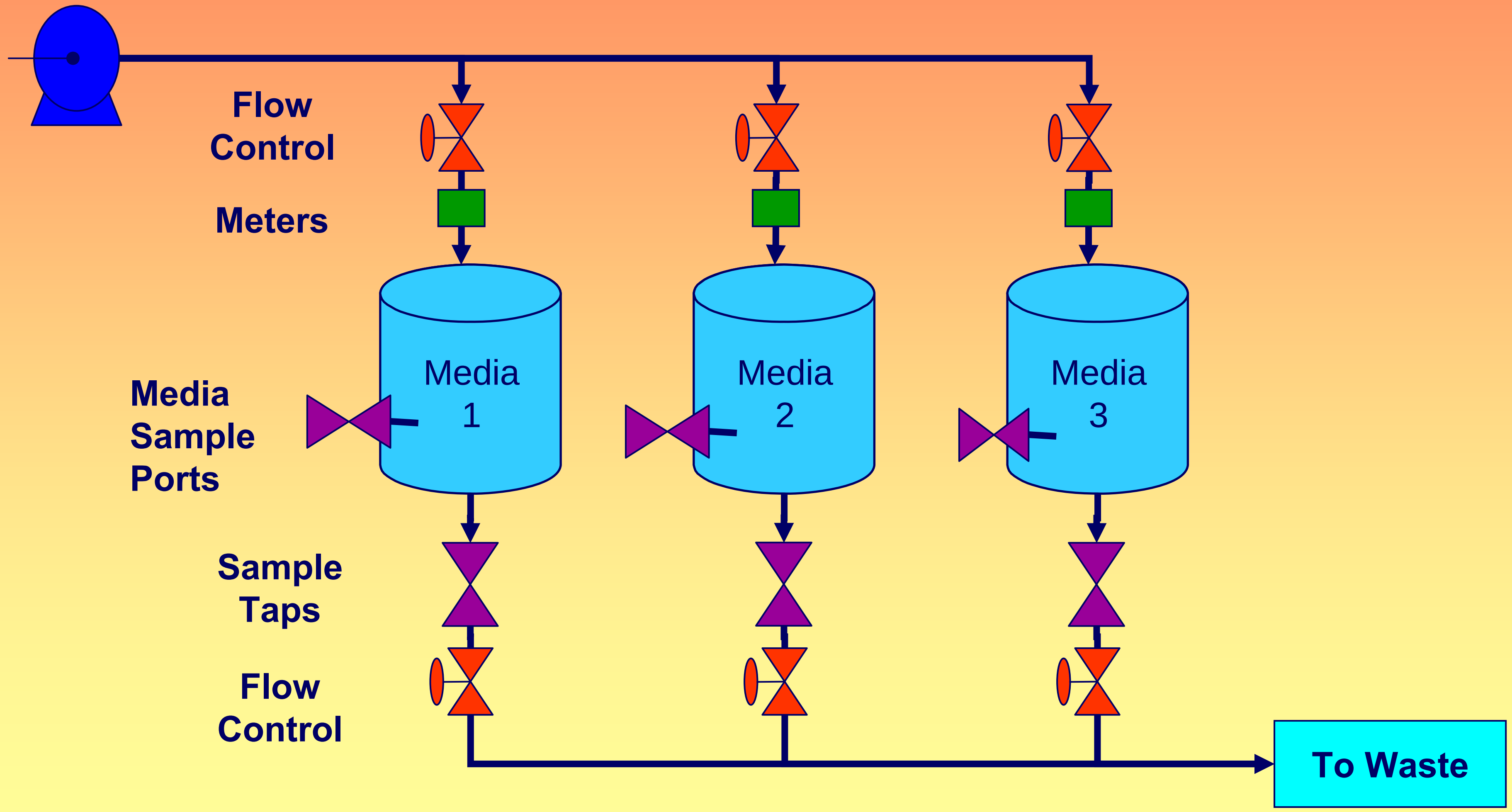
Establish a Protocol

- Introduction
- Objectives
- Media Description
- Process Description
- Project Schedule
- Project Documentation
- Data Collection
  - Parameters
  - Locations
  - Schedule
- Quality Assurance Program
- Residuals Management and Disposal
- Summary of the Pilot Study

Work with the State!

Pilot Plant

(parallel operation)



AWWARF Pilot Skid

Pilot Testing Considerations for Adsorption Systems

- Empty bed contact time (EBCT)
- Operating pH and chemical feed rates
- Is backwash necessary?
  - Flowrate and duration
- Filtration?
- Time to media
  - Breakthrough
  - Exhaustion
- Headloss conditions
- Residuals

Pilot Testing Considerations for Adsorption Systems

- Variations
  - Operate to exhaustion at natural pH
    - Collect data
    - Sample media and run TCLP
  - Adjust pH downward
    - Collect data
    - Sample media and run TCLP

4. Use a Reputable Vendor

- Water quality data
  - Must be accurate and representative
- Risks
  - It may not work
  - It may not be cost effective
- Protect yourself
  - Consider leasing arrangements
  - Guarantees

Questions for Vendors

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. **Develop construction cost estimates and plan**
11. **Implement the strategy**
12. **Monitor at entry point**

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan
11. **Implement the strategy**
12. **Monitor at entry point**

Project Timeline

Monitor and Determine Compliance Status

Select Engineer, Evaluate Options and Select Technology

Pilot Testing, Design, Vendor Selection, Cost Estimates

Permitting Process and Final Design

Fabricate and Deliver Equipment

Construction and Installation

Startup and Compliance

January 23, 2006

Interim Compliance Options

- Exemptions
  - Compliance schedule
- Administrative Orders
  - Compliance schedule
- Court Orders/Consent Decrees
  - Compliance schedule
  - Perhaps with stipulated penalties

Protect Yourself!

Mitigation Checklist

1. Monitor at entry points
2. Determine compliance status
3. Consider non-treatment options
4. Measure water quality parameters
5. Determine treatment evaluation criteria
6. Select a mitigation strategy
7. Estimate capital and O & M costs
8. Evaluate design considerations
9. Pilot test
10. Develop construction cost estimates and plan
11. Implement the strategy
12. **Monitor at entry point**

Compliance!